CHAPTER 27

NAVIGATION REGULATIONS

SHIP ROUTING

2700. Purpose And Types Of Routing Systems

Navigation, once truly independent throughout the world, is an increasingly regulated activity. The consequences of collision or grounding for a large, modern ship carrying tremendous quantities of high-value, perhaps dangerous cargo, are so severe that authorities have instituted many types of regulations and control systems to minimize the chances of loss. These range from informal and voluntary systems to closely controlled systems requiring compliance with numerous regulations. The regulations may concern navigation, communications, equipment, procedures, personnel, and many other aspects of ship management. This chapter will be concerned primarily with navigation regulations and procedures.

There are several specific types of regulation systems. For commonly used open ocean routes where risk of collision is present, the use of **recommended routes** separates ships going in opposite directions. In areas where ships converge at headlands, straits, and major harbors, **traffic separation schemes (TSS)** have been instituted to separate vessels and control crossing and meeting situations. Environmentally sensitive areas may be protected by **areas to be avoided** which prevent vessels of a certain size or carrying certain cargoes from navigating within specified boundaries. In confined waterways such as canals, lock systems, and rivers leading to major ports, local navigation regulations control ship movement.

2701. Definitions

The following terms relate to ship's routing:

Routing System: Any system of routes or routing measures designed to minimize the possibility of collisions between ships, including TSS's, two-way routes, recommended tracks, areas to be avoided, inshore traffic zones, precautionary areas, and deep-water routes.

Traffic Separation Scheme: A routing measure which separates opposing traffic flow with traffic lanes.

Separation Zone or Line: A zone or line which separates opposing traffic, separates traffic from adjacent areas, or separates different classes of ships from one another.

Traffic Lane: An area within which one-way traffic is established.

Roundabout: A circular traffic lane used at junctions of several routes, within which traffic moves counterclockwise around a separation point or zone.

Inshore Traffic Zone: The area between a traffic separation scheme and the adjacent coast, usually designated for coastal traffic.

Two-way Route: A two-way track for guidance of ships through hazardous areas.

Recommended Route: A route established for convenience of ship navigation, often marked with centerline buoys.

Recommended Track: A route, generally found to be free of dangers, which ships are advised to follow to avoid possible hazards nearby.

Deep-Water Route: A route surveyed and chosen for the passage of deep-draft vessels through shoal areas.

Precautionary Area: A defined area within which ships must use particular caution and should follow the recommended direction of traffic flow.

Area To Be Avoided: An area within which navigation by certain classes of ships is prevented because of particular navigational dangers or environmentally sensitive natural features.

Established Direction of Traffic Flow: The direction in which traffic within a lane must travel.

Recommended Direction of Traffic Flow: The direction in which traffic is recommended to travel.

There are various methods by which ships may be separated using Traffic Separation Schemes. The simplest

scheme might consist of just one method; more complex schemes will use several different methods together in a coordinated pattern to route ships to and from several areas at once. Schemes may be just a few miles in extent, or cover relatively large sea areas.

2702. Recommended Routes And Tracks

Recommended routes across the North Atlantic have been followed since 1898, when the risk of collision between increasing numbers of ships became too great, particularly at junction points. The International Convention for the Safety of Life at Sea (SOLAS) codifies the use of certain routes. These routes vary with the seasons, with winter and summer tracks chosen so as to avoid iceberg-prone areas. These routes are often shown on charts, particularly small scale ones, and are generally used to calculate distances between ports in tables.

Recommended routes consists of single tracks, either one-way or two-way. Two-way routes show the best water through confined areas such as inland routes among islands and reefs. Ships following these routes can expect to meet other vessels head-on and engage in normal passings. One-way routes are generally found in areas where many ships are on similar or opposing courses. They and are intended to separate opposing traffic so that most maneuvers are overtaking situations instead of the more dangerous meeting situation.

2703. Charting Recommended Routes

Recommended routes and recommended tracks are generally indicated on charts by black lines, with arrowheads indicating the desired direction of traffic. Not all recommended routes are charted. DMA charts generally depict recommended routes only on modified facsimiles made directly from foreign charts. In all cases, recommended routes are discussed in detail in the *Sailing Directions*.

TRAFFIC SEPARATION SCHEMES

2704. Traffic Separation Schemes (TSS)

In 1961, representatives from England, France, and Germany met to discuss ways to separate traffic in the congested Straits of Dover and subsequently in other congested areas. Their proposals were submitted to the International Maritime Organization (IMO) and were adopted in general form. IMO expanded on the proposals and has since instituted a system of **Traffic Separation Schemes (TSS)** throughout the world.

The IMO is the only international body responsible for establishing and recommending measures for ship's routing in international waters. It does not attempt to regulate traffic within the territorial waters of any nation.

In deciding whether or not to adopt a TSS, IMO considers the aids to navigation system in the area, the state of hydrographic surveys in the area, the scheme's adherence to accepted standards of routing, and the International Rules of the Road. The selection and development of TSS's are the responsibility of individual governments, who may seek IMO adoption of their plans, especially if the system extends into international waters.

Governments may develop and implement TSS's not adopted by the IMO, but in general only IMO-adopted schemes are charted. Rule 10 of the International Regulations for Preventing Collisions at Sea (Rules of the Road) addresses the subject of TSS's. This rule specifies the actions to be taken by various classes of vessels in and near traffic schemes.

Traffic separation schemes adopted by the IMO are listed in *Ship's Routing*, a publication of the IMO, 4 Albert Embankment, London SE1 7SR, United Kingdom. Because of differences in datums, chartlets in this publication which depict the various schemes must not be used either for navigation or to chart the schemes on navigational charts. The *Notice to Mariners* should be consulted for charting details.

2705. Methods Of Traffic Separation

A number of different methods of separating traffic have been developed, using various zones, lines, and defined areas. One or more methods may be employed in a given traffic scheme to direct and control converging or passing traffic. These are discussed below. Refer to definitions in section 2701.

Method 1. Separation of opposing streams of traffic by separation zones or lines. In this method, typically a central separation zone is established within which ships are not to navigate. The central zone is bordered by traffic lanes with established directions of traffic flow. The lanes are bounded on the outside by limiting lines.

Method 2. Separation of opposing streams of traffic by natural features or defined objects. In this method islands, rocks, or other features may be used to separate traffic. The feature itself becomes the separation zone.

Method 3. The separation of through traffic from local traffic by provision of inshore traffic zones. Outside of traffic schemes, ships may generally navigate in any direction. Inshore traffic zones provide an area within which local traffic may travel at will without interference with through

traffic in the lanes. Inshore zones are separated from traffic lanes by separation zones or lines.

Method 4. Division of traffic from several different direction into sectors. This approach is used at points of convergence such as pilot stations and major entrances.

Method 5. Routing traffic through junctions of two or more major shipping routes. The exact design of the scheme in this method varies with conditions. It may be a circular or rectangular precautionary area, a roundabout, or a junction of two routes with crossing routes and directions of flow well-defined.

2706. Representing TSS's On Charts

See Figure 2706. Depiction of TSS's on charts uses magenta (purple) as the primary color. Zones are shown by purple tint, limits are shown by T-dashes such as are used in other maritime limits, and lines are dashed. Arrows are open-lined or dashed-lined depending on use. Special provisions applying to a scheme may be mentioned in notes on the chart. Deep water routes will be marked with the designation "DW" in bold purple letters, and the least depth may be indicated.

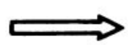
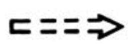
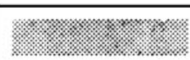
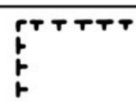
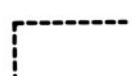
Routing term	Symbol	Description	Applications
1 Established direction of traffic flow		Outlined arrow	Traffic separation schemes and deep-water routes (when part of a traffic lane)
2 Recommended direction of traffic flow		Dashed outlined arrow	Precautionary areas, two-way routes, recommended routes and deep-water routes
3 Separation lines		Tint, 3 mm wide	Traffic separation schemes and between traffic separation schemes and inshore traffic zone
4 Separation zones		Tint, may be any shape	Traffic separation schemes and between traffic separation schemes and inshore traffic zones
5 Limits of restricted areas (charting term)		T-Shaped dashes	Areas to be avoided and defined ends of inshore traffic zones
6 General maritime limits (charting term)		Dashed line	Traffic separation schemes, precautionary areas, two-way routes and deep-water routes
7 Recommended tracks: one-way two-way		Dashed lines with arrowheads (colour black)	Generally reserved for use by charting authorities
8 Recommended routes		Dashed line and dashed outlined arrows	Recommended routes
9 Precautionary areas		Precautionary symbol	Precautionary areas

Figure 2706. Traffic separation scheme symbology. On charts the symbols are usually in magenta.

2707. Use Of Traffic Separation Schemes

A TSS is not officially approved for use until adopted by the IMO. Once adopted, it is implemented as of a certain time and date, as announced in the *Notice to Mariners* and perhaps through other means. The *Notice to Mariners* will also describe the scheme's general location and purpose and give specific directions in the chart correction section on plotting the various zones and lines which define it. These corrections usually apply to several charts. Because the charts may range in scale from quite small to very large, the corrections for each should be followed closely. The positions for the various features may be slightly different from chart to chart due to differences in rounding off positions or chart datum.

A TSS may be amended for periods of time ranging from a few hours to several years. Underwater construction works, surveying, dredging, and other transitory activities will be noted by radio broadcast, *Local Notice To Mariners*, or other means. Longer duration activities such as placement of oil drilling rigs, platforms, or pipelines may require a charted change to the scheme, which may become a permanent feature. These will be *Notice to Mariners* items.

Use of TSS's by all ships is recommended. They are intended for use in all weather, day and night. Adequate aids to navigation are a part of all TSS's. There is no special right of one ship over another in TSS's because the Rules of the Road apply in all cases. Deep-water routes should be avoided by ships which do not need them to keep them clear for deep-draft vessels. Ships need not keep strictly to the courses indicated by the arrows, but are free to navigate as necessary within their lanes to avoid other traffic. The signal "YG" is provided in the International Code of Signals to indicate to another ship: "You appear not to be complying with the traffic separation scheme."

TSS's are discussed in detail in the *Sailing Directions* for the areas where they are found.

2708. Areas To Be Avoided

Areas to be avoided are adopted by the IMO and are usually established to prevent possible grounding of tankers and other ships carrying hazardous cargo in environmentally sensitive areas. They may also be established to keep particular classes of ships away from areas where navigation is particularly hazardous.

They are depicted on charts by dashed lines or T-dashed lines, either point to point straight lines or as a circle centered on a feature in question such as a rock or island. The smallest may cover less than a mile in extent; the largest may cover hundreds of square miles of coral reefs or dangerous shoals. Notes on the appropriate charts and in Sailing Directions tell which classes of ships are excluded from the area.

2709. Special Rules

Certain special rules adopted by IMO apply in constricted areas such as the Straits of Malacca and Singapore, the English Channel and Dover Strait, and in the Gulf of Suez. These regulations are summarized in the appropriate *Sailing Directions (Planning Guides)*. For a complete summary of worldwide ships' routing measures, the IMO publication *Ship's Routing* should be obtained. See paragraph 2704.

VESSEL TRAFFIC SERVICES (VTS)

2710. Development And Purpose

The purpose of Vessel Traffic Services (VTS) is to provide active monitoring and navigational advice for vessels in particularly confined and busy waterways. There are two main types of VTS, surveilled and non-surveilled. Surveilled systems consist of one or more land-based radar sites which output their signals to a central location where operators monitor and to a certain extent control traffic flows. Non-surveilled systems consist of one or more calling-in points at which ships are required to report their identity, course, speed, and other data to the monitoring authority.

Vessel Traffic Services in the U.S. are implemented under the authority of the Ports and Waterways Safety Act of 1972 (Public Law 92-340 as amended) and the St. Lawrence Seaway Act (Public Law 358). They encompass a wide range of techniques and capabilities aimed at preventing vessel collisions, rammings, and groundings in the harbor/harbor approach and inland waterway phase of navigation. They are also designed to expedite ship movements, increase transportation system capacity, and improve all-weather operating capability.

A VHF-FM communications network forms the basis of most major services. Transiting vessels make position reports to an operations center by radiotelephone and are in turn provided with accurate, complete, and timely navigational safety information. The addition of a network of radars for surveillance and computer-assisted tracking and tagging, similar to that used in air traffic control, allows the VTS to play a more significant role in marine traffic management, thereby decreasing vessel congestion, critical encounter situations, and the probability of a marine casualty resulting in environmental damage. Surveilled VTS's are found in many large ports and harbors where congestion is a safety and operational hazard. Less sophisticated services have been established in other areas in response to hazardous navigational conditions according to the needs and resources of the authorities.

2711. Brief History Of VTS

Since the early 1960's the U.S. Coast Guard has been

investigating various concepts by which navigational safety can be improved in the harbor and harbor approach areas. Equipment installations in various ports for this investigation have included shore-based radar; low light level, closed-circuit television (LLL-CCTV); VHF-FM communications; broadcast television; and computer driven electronic situation displays.

In 1962 an experimental installation called **Ratan** (Radar and Television Aid to Navigation) was completed in New York Harbor. In this system a radar at Sandy Hook, New Jersey, scanned the approaches to the harbor. The radar video, formatted by a scan conversion storage tube, was broadcast by a television band UHF transmitter. This enabled mariners to observe on commercial television sets the presentation on the radarscope at Sandy Hook. The mariner could identify his vessel on the television screen by executing a turn and by observing the motions of the targets. The high persistency created by the scan converter provided target "tails" which aided in observing target movement. This Ratan experiment was discontinued primarily because of allocation of the commercial television frequency spectrum for other purposes.

In January 1970 the Coast Guard established a harbor radar facility in San Francisco to gather data on vessel traffic patterns. The information was used to determine parameters for new equipment procurements. The initial installation consisted of standard marine X-band (3-centimeter) search radars located on Point Bonita and Yerba Buena Island in San Francisco Bay. Radar video was relayed from these two radar sites to a manned center colocated with the San Francisco Marine Exchange. When the parameter definition work was completed, VHF-FM communications equipment was added to enable communications throughout the harbor area. This experimental system, previously called Harbor Advisory Radar (HAR) was designated in August 1972 as an operational Vessel Traffic System (VTS); a continuous radar watch with advisory radio broadcasts to traffic in the harbor was provided. This change from HAR to VTS coincided with the effective date of the Ports and Waterways Safety Act of 1972, authorizing the U.S. Coast Guard to install and operate such systems in United States waters to increase vessel safety and there by protect the environment.

In late 1972 improved developmental radar systems were installed side by side with the operational system, operated by a new research evaluation center at Yerba Buena Island. Redundant operator-switchable transceivers provided 50 kW peak power and incorporated receivers with large dynamic ranges of automatic gain control giving considerable protection against receiver saturation by interfering signals and interference by rain and sea clutter. Parabolic antennas with apertures of 27 feet (8.2 meters) and beam widths of 0.3 degrees improved the radar system accuracy. Variable pulse lengths (50 and 200 nanoseconds), three pulse repetition rates (1000, 2500, and 4000 pps), two receiver bandwidths (22 MHz and 2 MHz), and three antenna polarizations (horizontal, vertical, and circular) were provided to evaluate the optimum parameters for future procurements.

After a period of extensive engineering evaluation, the radar system was accepted in May 1973 as an operational replacement for the equipment installed earlier at the HAR.

In 1980 an analysis indicated that a modified version of the Coast Guard standard shipboard radar would meet all the VTS standard operating requirements. Additionally, it was more cost effective to procure and maintain than the specially designed, non-standard radar. After a period of evaluation at VTS San Francisco and with certain technical modifications, the standard radar was accepted for VTS use. The radar includes a tracking system which enhances the radar capability by allowing the VTS to track up to 20 targets automatically. The PPI can operate in an environment that is half as bright as a normal room with an option for a TV type display that can operate under any lighting conditions. These new radars are also required to provide data to a computer system, have 60 navigational line capability, and display ranges in yards or nautical miles.

The new radar was installed in VTS Prince William Sound in August 1984. VTS Houston-Galveston's radar was replaced in January 1985. VTS San Francisco radars were replaced in May 1985. VTS New York reopened in late 1990 and will continue to add coverage areas until the project is completed in 1995.

2712. Operational Systems

VTS New York became operational in December 1990. It had been open previously but was closed in 1988 due to a change in funding priorities.

This VTS has the responsibility of coordinating vessel traffic movements in the busy ports of New York and New Jersey. The VTS New York area includes the entrance to the harbor via Ambrose and Sandy Hook Channels, through the Verrazano Narrows Bridge to the Brooklyn Bridge in the East River, to the Holland Tunnel in the Hudson River, and the Kill Van Kull including Newark Bay. Future plans call for the VTS area to be expanded to include the East River to Throgs Neck, all of Arthur Kill, and Raritan Bay.

VTS New York is presently undergoing an upgrade which includes the installation of state-of-the-art equipment in a new operations center. The current operation uses surveillance data provided by 4 radar sites and 3 closed circuit TV sites. VTS communications are on VHF/FM channels 12 and 14.

VTS San Francisco was commissioned in August of 1972. When the original radar system became operational in May 1973, the control center for VTS San Francisco was shifted to the Yerba Buena Island. This center was designated a Vessel Traffic Center (VTC).

As of early 1985, the major components of the system include a Vessel Traffic Center at Yerba Buena Island, two high resolution radars, a VHF-FM communications network, a traffic separation scheme, and a vessel movement

reporting system (VMRS). Channels 12 and 14 are the working frequencies. In 1985, all existing radar equipment was replaced with the standard Coast Guard radar.

VTS San Francisco also operates an Offshore Vessel Movement Reporting System (OVMRS). The OVMRS is completely voluntary and operates using a broadcast system with information provided by participants.

VTS Puget Sound became operational in September 1972 as the second Vessel Traffic Service. It collected vessel movement report data and provided traffic advisories by means of a VHF-FM communications network. In this early service a VMRS was operated in conjunction with a Traffic Separation Scheme (TSS), without radar surveillance. Operational experience gained from this service and VTS San Francisco soon proved the expected need for radar surveillance in those services with complex traffic flow.

In 1973 radar coverage in critical areas of Puget Sound was provided. Efforts to develop a production generation of radar equipment for future port development were initiated. To satisfy the need for immediate radar coverage, redundant military grade Coast Guard shipboard radar transceivers were installed at four Coast Guard light stations along the Admiralty Inlet part of Puget Sound. Combination microwave radio link and radar antenna towers were installed at each site. Radar video and azimuth data, in a format similar to that used with VTS San Francisco, were relayed by broad band video links to the VTC in Seattle. At that Center, standard Navy shipboard repeaters were used for operator display. Although the resolution parameters and display accuracy of the equipment were less than those of the VTS San Francisco equipment, the use of a shorter range scale (8 nautical miles) and overlapping coverage resulted in very satisfactory operation. In December 1980 additional radar surveillance was added in the Strait of Juan De Fuca and Rosario Strait, as well as increased surveillance of the Seattle area, making a total of 10 remote radar sites.

The communications equipment was upgraded in July 1991 to be capable of a two frequency, four sector system. Channels 5A and 14 are the frequencies for VTS Puget Sound. A total of 13 Communication sites are in operation (3 extended area sites, 10 low level sites). The 3 extended area sites allow the VTS the ability to communicate in a large area when needed. The low level sites can be used in conjunction with one another without interference, and have greatly reduced congestion on the frequency. VTS Puget Sound now covers the Strait of Juan de Fuca, Rosario Strait, Admiralty Inlet, and Puget Sound south as far as Olympia.

The major components of the system include the Vessel Traffic Center at Pier 36 in Seattle; a VHF-FM communications network; a traffic separation scheme; radar surveillance of about 80% of the VTS area, and a Vessel Movement Reporting System. Regulations are in effect which require certain classes of vessels to participate in the system and make movement reports at specified points. The traffic separation scheme in the Strait of Juan de Fuca was extended as far west as Cape Flattery in March 1975 in cooperation with Canada and was formally adopted by the International Maritime Organization in 1982.

Under an agreement between the United States and Canada, regulations for the Strait of Juan de Fuca took effect in 1984. The Cooperative Vessel Traffic Management System (CVTMS) divides responsibility among the two Canadian VTS's and VTS Puget Sound.

VTS Houston-Galveston became operational in February 1975 as the third Vessel Traffic Service. The operating area is the Houston Ship Channel from the sea buoy to the Turning Basin (a distance of 53 miles) and the side channels to Galveston, Texas City, Bayport, and the Intracoastal Waterway. The area contains approximately 70 miles of restricted waterways. The greater part of the Houston Ship Channel is 400 feet wide with depths of 36-40 feet. Several bends in the channel are in excess of 90 degrees.

The major components of the system include the VTC at Galena Park, Houston; a VHF-FM communications network; low light level, closed circuit television (LLL-CCTV) surveillance covering approximately 3 miles south of Morgan's Point west through the ship channel to City Dock #27 in Houston; a Vessel Movement Reporting System; and a radar surveillance system covering lower Galveston Bay approaches, Bolivar Roads, and Lower Galveston Bay.

A second radar was installed in 1994. This radar will provide surveillance coverage between the Texas City channel and Morgan's Point.

VTS Prince William Sound is required by The Trans-Alaska Pipeline Authorization Act (Public Law 93-153), pursuant to authority contained in Title 1 of the Ports and Waterways Safety Act of 1972 (86 Stat. 424, Public Law 92-340).

The southern terminus of the pipeline is on the south shoreline of Port Valdez, at the Alyeska Pipeline Service Company tanker terminal. Port Valdez is at the north end of Prince William Sound, and Cape Hinchinbrook is at the south entrance.

Geographically, the area is comprised of deep open waterways surrounded by mountainous terrain. The only constrictions to navigation are at Cape Hinchinbrook, the primary entrance to Prince William Sound, and at Valdez Narrows, the entrance to Port Valdez.

The vessel traffic center is located in Valdez. The system is composed of two radars, two major microwave data relay systems, and a VMRS which covers Port Valdez, Prince William Sound, and Gulf of Alaska. There is also a vessel traffic separation scheme from Cape Hinchinbrook to Valdez Arm.

The Coast Guard is installing a dependent surveillance system to improve its ability to track tankers transiting Prince William Sound. To extend radar coverage the length of the traffic lanes in Prince William Sound would require several radars at remote, difficult-to-access sites and an extensive data relay network. As an alternative to radar, the Coast Guard is installing a dependent surveillance system that will require vessels to carry posi-

tion and identification reporting equipment. The ability to supplement radar with dependent surveillance will bridge the gap in areas where conditions dictate some form of surveillance and where radar coverage is impractical. Once the dependent surveillance information is returned to the vessel traffic center, it will be integrated with radar data and presented to the watchstander on an electronic chart display.

REGULATED WATERWAYS

2713. Purpose And Authorities

In confined waterways not considered international waters, local authorities may establish certain regulations for the safe passage of ships and operate waterway systems consisting of locks, canals, channels, and ports. This occurs generally in very busy or very highly developed waterways which form the major constrictions on international shipping routes. The Panama Canal, St. Lawrence Seaway, and the Suez Canal represent systems of this type. Nearly all ports and harbors have a body of regulations concerning the operation of vessels within the port limits, particularly if locks and other structures are part of the system. The regulations covering navigation through these areas are typically part of a much larger body of regulations relating to assessment and payment of tariffs and tolls, vessel condition and equipment, personnel, communications equipment, and many other factors. In general the larger the investment in the system, the larger will be the body of regulations which control it.

Where the waterway separates two countries, a joint authority may be established to administer the regulations, collect tolls, and operate the system, as in the St. Lawrence Seaway.

Copies of the regulations are usually required to be aboard each vessel in transit. These regulations are available from the authority in charge or an authorized agent. Summaries of the regulations are contained in the appropriate volumes of the *Sailing Directions (Enroute)*.

CHAPTER 28

GLOBAL MARITIME DISTRESS AND SAFETY SYSTEM

DEVELOPMENT

2800. Introduction

The **Global Maritime Distress and Safety System (GMDSS)** represents a significant improvement in marine safety over the previous system of short range and high seas radio transmissions. Its many parts include satellite as well as advanced terrestrial communications systems. Operational service of the GMDSS began on 1 February 1992, with full implementation scheduled by 1 February 1999.

2801. Background

The GMDSS was adopted by amendments in 1988 by the Conference of Contracting Governments to the International Convention for the Safety of Life at Sea (SOLAS), 1974. This was the culmination of more than a decade of work by the International Maritime Organization (IMO) in conjunction with the International Telecommunications Union (ITU), International Hydrographic Organization (IHO), World Meteorological Organization (WMO), International Maritime Satellite Organization (INMARSAT), and others.

The GMDSS offers the greatest advancement in maritime safety since the enactment of regulations following the Titanic disaster in 1912. It is an automated ship-to-ship, shore-to-ship and ship-to-shore system covering distress alerting and relay, the provision of **maritime safety information (MSI)** and basic communication links. Satellite and advanced terrestrial systems are incorporated into a modern communications network to promote and improve safety of life and property at sea throughout the world. The equipment required on board ships will depend not on their tonnage, but rather on the sea area in which the vessel operates. This is fundamentally different from the previous system, which based requirements on vessel size alone. The greatest benefit of the GMDSS is that it vastly reduces the chances of ships sinking without a trace and enables search and rescue (SAR) operations to be launched without delay.

SHIP REQUIREMENTS

2802. Ship Carriage Requirements

By the terms of the SOLAS Convention, the GMDSS provisions apply to cargo ships of 300 gross tons and over and ships carrying more than 12 passengers on international voyages. Unlike previous shipboard carriage regulations that specified equipment according to *size* of vessel, the GMDSS carriage requirements stipulate equipment according to the *area* the vessel operates in. These sea areas are designated as follows:

Sea Area A1 An area within the radiotelephone coverage of at least one VHF coast station in which continuous Digital Selective Calling (DSC - a radio receiver that performs distress alerting and safety calling on HF, MF and VHF frequencies) is available, as may be defined by a Contracting Government to the 1974 SOLAS Convention. This area extends from the coast to about 20 miles offshore.

Sea Area A2 An area, excluding sea area A1, within the radiotelephone coverage of at least one MF coast station in which continuous DSC alerting is available, as may be defined by a Contracting Government. The general area is from the A1 limit out to about 100 miles offshore.

Sea Area A3 An area, excluding sea areas A1 and A2, within the coverage of an INMARSAT geostationary satellite in which continuous alerting is available. This area is from about 70°N to 70°S.

Sea Area A4 All areas outside of sea areas A1, A2 and A3. This area includes the polar regions, where geostationary satellite coverage is not available.

Ships at sea must be capable of the following functional GMDSS requirements:

1. Ship-to-shore distress alerting.
2. Shore-to-ship distress alerting.
3. Ship-to-ship distress alerting.
4. SAR coordination.
5. On-scene communications.
6. Transmission and receipt of emergency locating signals.
7. Transmission and receipt of MSI.
8. General radio communications.
9. Bridge-to-bridge communications.

To meet the requirements of the functional areas above the following is a list of the minimum communications equipment needed for all ships:

1. VHF radio capable of transmitting and receiving DSC on channel 70 and radio telephony on channels 6, 13 and 16.
2. Radio receiver capable of maintaining a continuous DSC watch on channel 70 VHF.
3. Search and rescue transponders (SART), a minimum of two, operating in the 9 GHz band.
4. Receiver capable of receiving NAVTEX broadcasts anywhere NAVTEX service is available.
5. Receiver capable of receiving SafetyNET anywhere NAVTEX is not available.
6. Satellite emergency position indicating radiobeacon (EPIRB), manually activated or float-free self-activated.
7. Two-way handheld VHF radios (two sets minimum on 300-500 gross tons cargo vessels and three sets minimum on cargo vessels of 500 gross tons and upward and on all passenger ships).
8. Until 1 Feb. 1999, a 2182 kHz watch receiver.

Additionally, each sea area has its own requirements under GMDSS which are as follows:

Sea Area A1

1. General VHF radio telephone capability.
2. Free-floating EPIRB transmitting DSC on channel 70 VHF, or satellite EPIRB.
3. Capability of initiating a distress alert from a navigational position using DSC on either VHF, HF or MF; manually activated EPIRB; or Ship Earth Station (SES).

Sea Areas A1 and A2

1. Radio telephone MF 2182 kHz and DSC on 2187.5 kHz.
2. Equipment capable of maintaining a continuous DSC watch on 2187.5 kHz.
3. General working radio communications in the MF band 1605-4000 kHz, or INMARSAT SES.
4. Capability of initiating a distress alert by HF (using DSC), manual activation of an EPIRB, or INMARSAT SES.

Sea Areas A1, A2 and A3

1. Radio telephone MF 2182 kHz and DSC 2187.5 kHz.
2. Equipment capable of maintaining a continuous DSC watch on 2187.5 kHz.
3. INMARSAT A, B or C (class 2) SES Enhanced Group Call (EGC), or HF as required for sea area A4.
4. Capability of initiating a distress alert by two of the following:
   a. INMARSAT A, B or C (class 2) SES.
   b. Manually activated satellite EPIRB.
   c. HF/DSC radio communication.

Sea Area A4

1. HF/MF receiving and transmitting equipment for band 1605-27500 kHz using DSC, radiotelephone and direct printing.
2. Equipment capable of selecting any safety and distress DSC frequency for band 4000-27500 kHz, maintaining DSC watch on 2187.5, 8414.5 kHz and at least one additional safety and distress DSC frequency in the band.
3. Ability to initiate a distress alert from a navigational position via the Polar Orbiting System on 406 MHz (manual activation of 406 MHz satellite EPIRB).

COMMUNICATIONS

2803. The INMARSAT System

The **International Maritime Satellite Organization (INMARSAT)**, a key player within GMDSS, is an international consortium comprising over 75 international partners who provide maritime safety communications for ships at sea. In accordance with its convention, INMARSAT provides the space segment necessary for improving distress communications, efficiency and management of ships, as well as maritime correspondence services.

The basic components of the INMARSAT system include the INMARSAT **space segment, Land Earth Stations (LES)**, also referred to as **Coast Earth Stations (CES)**, and mobile **Ship Earth Stations (SES)**.

The INMARSAT space segment consists of 11 geostationary satellites. Four operational INMARSAT satellites provide primary coverage, four additional satellites (including satellites leased from the European Space Agency (ESA) and the International Telecommunications Satellite Organization (INTELSAT)) serve as spares and three remaining satellites (leased from COMSAT Corporation, the U.S. signatory to INMARSAT) serve as back-ups.

The polar regions are not visible to the operational satellites and coverage is available from 70°N to 70°S. Satellite coverage (Figure 2803) is divided into four regions, which are:

1. Atlantic Ocean - East (AOR-E)
2. Atlantic Ocean - West (AOR-W)
3. Pacific Ocean (POR)
4. Indian Ocean (IOR)

The LES's provide the link between the Space Segment and the land-based National/International fixed communications networks. These communications networks are funded and operated by the authorized communications authorities of a participating nation. This network links registered information providers to the LES. The data then travels from the LES to the INMARSAT **Network Coordination Station (NCS)** and then down to the SES's on ships at sea. The SES's provide two-way communications between ship and shore. **INMARSAT A**, the original INMARSAT system, operates at a transfer rate of up to 9600 bits per second and is telephone, telex and facsimile (fax) capable. It is being replaced by a similarly sized **INMARSAT B** system that uses digital technology to give better quality fax and higher data transmission rates.

INMARSAT C provides a **store and forward** data messaging capability (but no voice) at 600 bits per second and was designed specifically to meet the GMDSS requirements for receiving MSI data on board ship. These units are small, lightweight and use an omni-directional antenna.

2804. SafetyNET

SafetyNET is a service of INMARSAT C's **Enhanced Group Call (EGC)** system. The EGC system (Figure 2804) is a method used to specifically address particular regions or ships. Its unique addressing capabilities allow messages to be sent to all vessels in both fixed geographical areas or to predetermined groups of ships. SafetyNET is the service designated by the IMO through which ships receive maritime safety information. The other service under the EGC system, called **FleetNET**, is used by commercial companies to directly (and privately) communicate to their individual fleets.

SafetyNET is an international direct-printing satellite-based service for the promulgation of navigational and meteorological warnings, and distress alerts, forecasts, and other safety messages. It fulfills an integral role in GMDSS as developed by the IMO. The ability to receive SafetyNET service information is necessary for all ships that sail beyond coverage of NAVTEX (approximately 200 miles from shore) and is recommended to all administrations having the

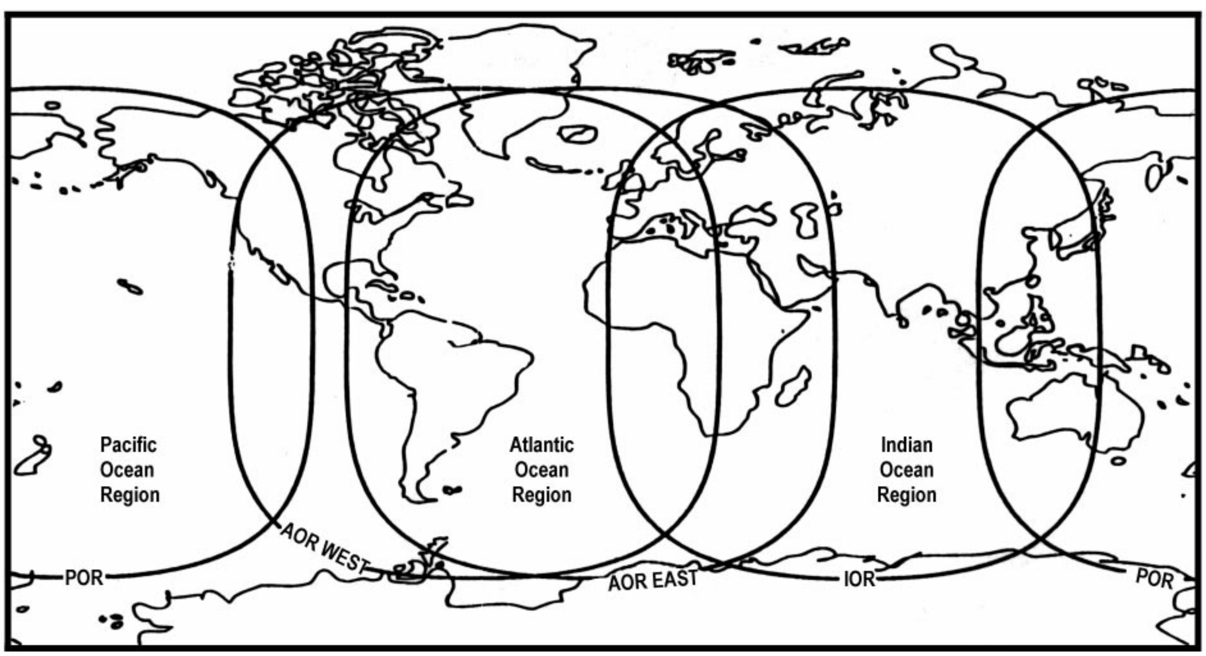


Figure 2803. The four regions of INMARSAT coverage.

responsibility for marine affairs and mariners who require effective MSI service in waters not served by NAVTEX.

SafetyNET can direct a message to a given geographic area based on EGC addressing. The area may be fixed, as in the case of a NAVAREA or weather forecast area, or it may be uniquely defined by the originator. This is particularly useful for messages such as local storm warnings or a ship-to-shore distress alert for which it would be inappropriate to alert ships in an entire ocean region.

SafetyNET messages can be originated by a **Registered Information Provider** anywhere in the world and broadcast to the appropriate ocean area through an INMARSAT-C LES. Messages are broadcast according to their priority (i.e., Distress, Urgent, Safety, and Routine).

Virtually all navigable waters of the world are covered by the operational satellites in the INMARSAT system. Each satellite broadcasts EGC traffic on a designated channel. Any ship sailing within the coverage area of an INMARSAT satellite will be able to receive all the SafetyNET messages broadcast over this channel. The EGC channel is optimized to enable the signal to be monitored by SES's dedicated to the reception of EGC messages. This capability can be built into other standard SES's. It is a feature of satellite communications that reception is not generally affected by the position of the ship within the ocean region, atmospheric conditions, or time of day.

Messages can be transmitted either to geographic areas (area calls) or to groups of ships (group calls):

1. **Area calls** can be to a fixed geographic area such as one of the 16 NAVAREA's or to a temporary geographic area selected by the originator. Area calls will be received automatically by any ship whose receiver has been set to one or more fixed areas or recognizes an area by geographic position.

2. **Group calls** will be received automatically by any ship whose receiver acknowledges the unique group identity associated with a particular message.

Reliable delivery of messages is ensured by forward error correction techniques. Experience has demonstrated that the transmission link is generally error-free and low error reception is achieved under normal circumstances.

Given the vast ocean coverage by satellite, some form of discrimination and selectivity in printing the various messages is required. Area calls will be received by all ships within the ocean region coverage of the satellite; however, they will be printed only by those receivers that recognize the fixed area or the geographic position in the message. The message format includes a **preamble** that enables the microprocessor in a ship's receiver to decide to print those MSI messages that relate to the present position, intended route or a fixed area programmed by the operator. This preamble also allows suppression of certain types of MSI that are not relevant to a particular ship. As each message will also have a

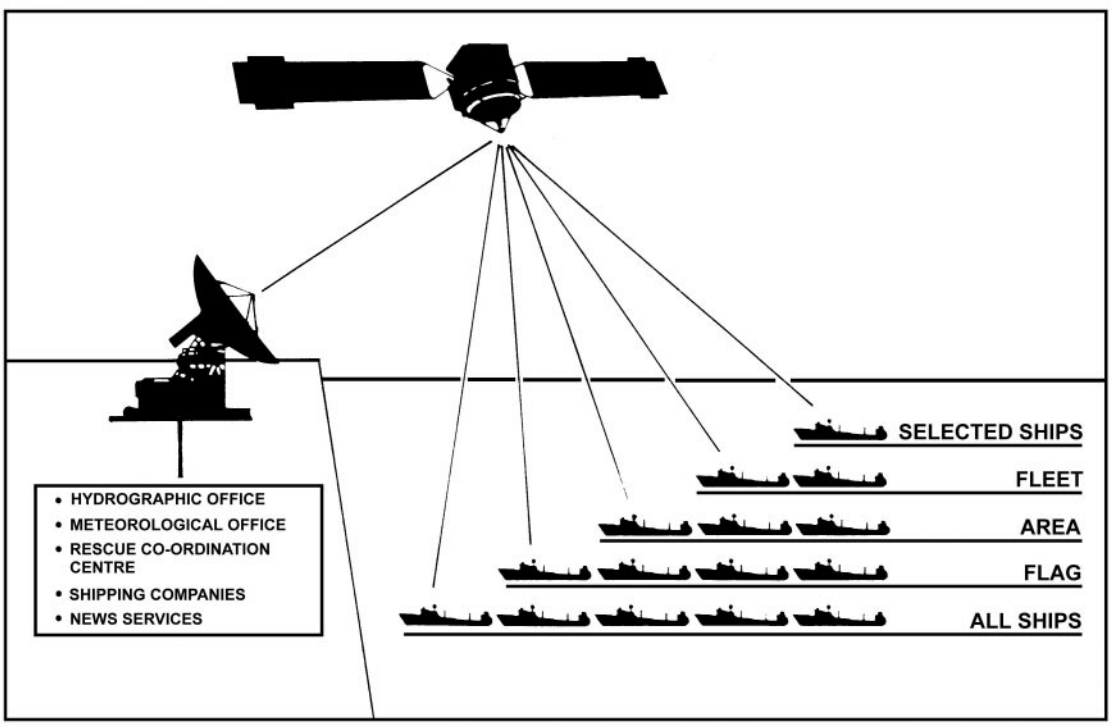


Figure 2804. SafetyNET EGC concept.

unique identity, the reprinting of messages already received correctly is automatically suppressed.

MSI is promulgated by various information providers around the world. Messages for transmission through the SafetyNET service will, in many cases, be the result of coordination between authorities. Information providers will be authorized to broadcast via SafetyNET by IMO. Authorized information providers are:

1. National hydrographic offices for navigational warnings.
2. National weather services for meteorological warnings and forecasts.
3. Rescue Coordination Centers for ship-to-shore distress alerts and other urgent information.
4. In the U.S., the International Ice Patrol for North Atlantic ice hazards.

Each information provider prepares their SafetyNET messages with certain characteristics recognized by the EGC service. These characteristics, known as "C" codes are combined into a generalized message header format as follows: C1:C2:C3:C4:C5. Each "C" code controls a different broadcast criterion and is assigned a numerical value according to available options. A sixth "C" code, "C0" may be used to indicate the ocean region (i.e., AOR-E, AOR-W, POR, IOR) when sending a message to an LES which operates in more than one ocean region. Because errors in the header format of a message may prevent its being released, MSI providers must install an INMARSAT SafetyNET receiver to monitor the broadcasts it originates. This also ensures quality control.

The "C" codes are transparent to the mariner but are used by information providers to identify various transmitting parameters. C1 designates the message priority from distress to urgent, safety, and routine. MSI messages will always be at least at the safety level. C2 is the service code or type of message (for example, long range NAVAREA warning or coastal NAVTEX warning). It also tells the receiver the length of the address (the C3 code) it will need to decode. C3 is the address code. It can be the two digit code for the NAVAREA number for instance, or a 10 digit number to indicate a circular area for a meteorological warning. C4 is the repetition code which instructs the LES in how long and when to send the message to the NCS for actual broadcast. A six minute echo (repeat) may also be used to ensure that an urgent (unscheduled) message has been received by all ships affected. C5 is a constant and represents a presentation code, International Alphabet number 5, "00".

Broadcasts of MSI in the international SafetyNET service are in English.

2805. NAVTEX

NAVTEX is a maritime radio warning system consisting of a series of coast stations transmitting radio teletype (standard narrow-band direct printing, also sometimes called **Sitor**) safety messages on the internationally standard medium frequency of 518 kHz. It is a GMDSS requirement for the reception of MSI in coastal and local waters. Coast stations transmit during previously arranged time slots to minimize mutual interference. Routine messages are normally broadcast four times daily. Urgent messages are broadcast upon receipt, provided that an adjacent station is not transmitting. Since the broadcast uses the medium frequency band, a typical station service radius ranges from 100 to 500 NM day and night (although a 200 mile rule of thumb is applied in the U.S.). Interference from or receipt of stations farther away occasionally occurs at night.

Each NAVTEX message broadcast contains a four-character header describing: identification of station (first character); message content or type (second character); and message serial number (third and fourth characters). This header allows the microprocessor in the shipboard receiver to screen messages from only those stations relevant to the user, messages of subject categories needed by the user and messages not previously received by the user. Messages so screened are printed as they are received, to be read by the mariner when convenient. All other messages are suppressed. Suppression of unwanted messages is becoming more and more a necessity to the mariner as the number of messages, including rebroadcast messages, increases yearly. With NAVTEX, a mariner will not find it necessary to listen to, or sift through, a large number of non-relevant data to obtain the information necessary for safe navigation.

The NAVTEX receiver is a small unit with an internal printer, which takes a minimum of room on the bridge. Its antenna is also of modest size, needing only a receive capability.

2806. Maritime Safety Information (MSI)

Major categories of MSI for both NAVTEX and SafetyNET are:

1. Navigational warnings
2. Meteorological warnings
3. Ice reports
4. Search and rescue information
5. Meteorological forecasts
6. Pilot service messages (not in the U.S.)
7. Electronic navigation system messages (i.e., OMEGA, LORAN, DECCA, GPS, DGPS, SATNAV, etc.)

Broadcasts of MSI in NAVTEX international service are in English, but may be in languages other than English, to meet requirements of the host government.

2807. Digital Selective Calling (DSC)

Digital Selective Calling (DSC) is a method of auto-

matically placing a call directly from one radio to another. This is accomplished by addressing the call so it will be received automatically by the other radio. It permits a radio to be used like a telephone. Since the DSC system will sound an alarm (much like a ringing telephone) when it senses an incoming call, there is no need for dedicated, aural watch-standing. DSC techniques can be used with VHF, HF and MF radio communications. DSC's principal uses are in distress alerting and safety calling. Numerous frequencies have been assigned. They are 2187.5 kHz in the MF band; 4207.5 kHz, 6312 kHz, 8414.5 kHz, 12577 kHz and 16804.5 kHz in the HF band; and 156.525 MHz (channel 70) in the VHF band.

2808. Emergency Position-Indicating Radio Beacons

Emergency Position-Indicating Radio Beacons (EPIRBs) are designed to transmit a satellite alert in the event of sudden accident either automatically or manually. The automatic models are designed and mounted so that they will float free of a sinking vessel and be activated by seawater. The manual ones are controlled by a switch. Under GMDSS, satellite EPIRBs will operate either on 1.6 GHz (the INMARSAT E, L Band) or the 406 MHz frequency used by the COSPAS-SARSAT system.

GMDSS requires 1 satellite EPIRB along with 2 search and rescue transponders (SART's). These SART's generate a series of response signals when interrogated by any ordinary 9 GHz radar set. The signals produce a line of 20 blips on the radar screen of the rescue ship or aircraft.

Under GMDSS, the COSPAS-SARSAT and INMARSAT communication systems are the two basic media through which the EPIRB signal is relayed to ground and sea stations. COSPAS-SARSAT is a joint international satellite-aided SAR system operated by multi-national organizations in Canada, France, the U.S. and the Russian Federation. It uses low polar orbiting satellites which receive and relay distress signals from EPIRBs and determine their position. INMARSAT, with over 75 member nations, operates a global satellite EPIRB system (excluding the poles). Further details of the COSPAS-SARSAT system are found in Chapter 29, Position Reporting Systems.

CHAPTER 29

POSITION REPORTING SYSTEMS

INTRODUCTION

2900. Purpose

The purpose of position reporting systems is to monitor vessel positions and inform authorities and other vessels of an emergency or distress at sea so that a response can be coordinated among those best able to help. It is important that distress information be immediately available to Search and Rescue (SAR) coordinators so that assistance can be obtained with the least delay. Establishing communications is sometimes difficult even when automatic alarms are used, and determination of SAR capabilities and intentions of vessels is time-consuming, unless the essential information has been made readily available beforehand by their participation in a position reporting system.

The Convention on Safety of Life at Sea (SOLAS) obligates the master of any vessel who becomes aware of a distress incident to proceed to the emergency and assist until other aid is at hand or until released by the distressed vessel. Other international treaties and conventions impose the same requirement. Position reporting systems permit determination of the most appropriate early assistance, provide the means for a timely resolution of distress cases, and enable vessels responding to distress calls to continue their passage with a minimum amount of delay.

Other resolutions recommend that governments encourage participation in position reporting schemes by ensuring that no costs are incurred by the vessel for participation.

There are currently many position reporting systems in operation throughout the world. The particulars of each system are given in publications of the International Maritime Organization (IMO). Masters of vessels making offshore passages are requested by the U.S. Coast Guard to always participate in the AMVER System and to participate in the other systems when in the areas covered by them.

AMVER

2901. The Automated Mutual-Assistance Vessel Rescue System (AMVER)

AMVER, operated by the United States Coast Guard, is an international maritime mutual assistance program which assists search and rescue efforts in many offshore areas of the world. Merchant ships of all nations making offshore passages are encouraged to send movement (sailing) reports and periodic position reports voluntarily to the AMVER Center in New York via selected radio stations. Information from these reports is entered into a computer which maintains dead reckoning positions for the vessels.

Information concerning the predicted location and SAR characteristics of each vessel is available upon request to recognized SAR agencies of any nation or to vessels needing assistance. Predicted locations are disclosed only for reasons related to marine safety.

Messages sent within the AMVER System are at no cost to the ship or owner. Benefits to shipping include: (1) improved chances of aid in emergencies, (2) reduced number of calls for assistance to vessels not favorably located, and (3) reduced time lost for vessels responding to calls for assistance. An AMVER participant is under no greater obligation to render assistance during an emergency than a non-participating vessel.

All AMVER messages are addressed to Coast Guard, New York, regardless of the station to which the message is delivered, except those sent to Canadian stations which should be addressed to AMVER Halifax or AMVER Vancouver. This avoids incurring charges to the vessel.

In addition to the information calculated from sailing plans and position reports, the AMVER Center stores data on the characteristics of vessels. This includes the following: vessel name; international call sign; nation of registry; owner or operator; type of rig; type of propulsion; gross tonnage; length; normal cruising speed; radio schedule; radio facilities; radio telephone installed; surface search radar installed; doctor normally carried. Vessels can assist the AMVER Center in keeping this data accurate by sending a complete report by message, letter, or by completing a SAR Information Questionnaire available from AMVER, and sending corrections as the characteristics change. Corrections may be included in regular AMVER reports as remarks.

For AMVER participants bound for U.S. ports there is an additional benefit. AMVER messages which include the necessary information are considered to meet the requirements of 33 CFR 161 (Notice of arrival).

2902. AMVER System Communications Network

An extensive radio network supports the AMVER system. Propagation conditions, location of vessel, and message density will normally determine which station should be contacted to establish communications. To ensure that no charge is applied, all AMVER messages should be passed through specified radio

stations. Those which currently accept AMVER messages and apply to coastal station, ship station, or landline charge are listed in each issue of the AMVER Bulletin, together with respective call sign, location, frequency bands, and hours of guard. Although AMVER messages may be sent through other stations, the Coast Guard cannot reimburse the sender for any charges.

2903. The AMVER Bulletin

The **AMVER Bulletin**, published quarterly by the U.S. Coast Guard, provides information on the operation of the AMVER System of general interest to the mariner. It also provides up-to-date information on the AMVER communications network and Radio Wave Propagation Charts which indicate recommended frequencies for contacting U.S. coast radio stations participating in the AMVER System, according to the time of day and the season of the year.

2904. AMVER Participation

Instructions guiding participation in the AMVER System are available in the following languages: Chinese, Danish, Dutch, English, French, German, Greek, Italian, Japanese, Korean, Norwegian, Polish, Portuguese, Russian, Spanish and Swedish. The AMVER Users Manual is available from: Commander, Atlantic Area, U.S. Coast Guard, Governors Island, NY, 10004; Commander Pacific Area, U.S. Coast Guard, Government Island, Alameda, CA 94501; and at U.S. Coast Guard District Offices, Marine Safety Offices, Marine Inspection Offices and Captain of the Port Offices in major U.S. ports. Requests for instructions should state the language desired if other than English.

Search and Rescue operation procedures are contained in the *Merchant Ship Search and Rescue Manual* (MERSAR) published by the International Maritime Organization (IMO). U.S. flag vessels may obtain a copy of MERSAR from local Coast Guard Marine Safety Offices and Marine Inspection Offices or by writing to U.S. Coast Guard (G-OSR), Washington, DC 20593. Other flag vessels may purchase MERSAR directly from IMO.

In connection with a vessel's first AMVER-plotted voyage, the master is requested to complete a questionnaire providing the radio watch schedule, available medical and communications facilities, and other useful characteristics. Stored in the AMVER computer, this information can be electronically processed in an emergency, while a position is calculated.

Any vessel of any nation departing on an offshore passage of 24 hours duration or greater is encouraged to become a participant in the AMVER System by sending appropriate AMVER messages in one of several formats. The messages may be transmitted at any convenient time as long as the information is accurate.

There are five types of AMVER Reports.

1. Sailing Plan.
2. Departure Report.
3. Arrival Report.
4. Position Report.
5. Deviation Reports.

AMVER permits sailing plan and departure information to be combined into a single report. It also accepts sailing plan information separately.

Only the above five types of AMVER messages require specific formats. (See DMAHTC *Pub. 117, Radio Navigational Aids*). Other messages relating to a vessel's AMVER participation or data, such as facts on her SAR capabilities, may also be sent via the AMVER communications network.

Additional information concerning the AMVER System may be obtained by writing to: Commandant, U.S. Coast Guard, Washington, DC 20590, or by writing or visiting Commander, Atlantic Area, U.S. Coast Guard, Governors Island, New York, NY 10004. The AMVER System in the Pacific is coordinated by Commander, Pacific Area, U.S. Coast Guard, Government Island, Alameda, CA 94501.

Other countries such as Canada are a formal part of the AMVER System and provide radio stations for relay of AMVER reports, as well as coordinating rescue efforts in certain regions. Applicable instructions have been promulgated by official publications of the participating countries.

2905. AMVER Reporting Required

The U.S. Maritime Administration regulations state that certain U.S. flag vessels and foreign flag "War Risk" vessels must report and regularly update their voyages to the AMVER Center. This reporting is required of the following: (a) U.S. flag vessels of 1,000 tons or greater, operating in foreign commerce; (b) foreign flag vessels of 1,000 gross tons or greater, for which an Interim War Risk Insurance Binder has been issued under the provisions of Title XII, Merchant Marine Act, 1936.

2906. AMVER Plot Information

The information stored in the computer can be used to provide several types of display according to the needs of controllers at Rescue Coordination Centers. The surface picture (SURPIC) can be displayed as a **Radius SURPIC** (Figure 2906a). When requesting a Radius SURPIC, the controller specifies the date and time, a latitude and longitude to mark the center (P), the radius (in nautical miles) that the SURPIC should cover (R), and whether the names of all ships are desired (or only those with doctors, or perhaps those heading either east or west).

A Radius SURPIC may be requested for any radius from 1 to 999 miles. A sample request is as follows:

"REQUEST 062100Z RADIUS SURPIC OF DOCTORSHIPS WITHIN 800 MILES OF 43.6N 030.2W FOR MEDICAL EVALUATION M/V SEVEN SEAS."

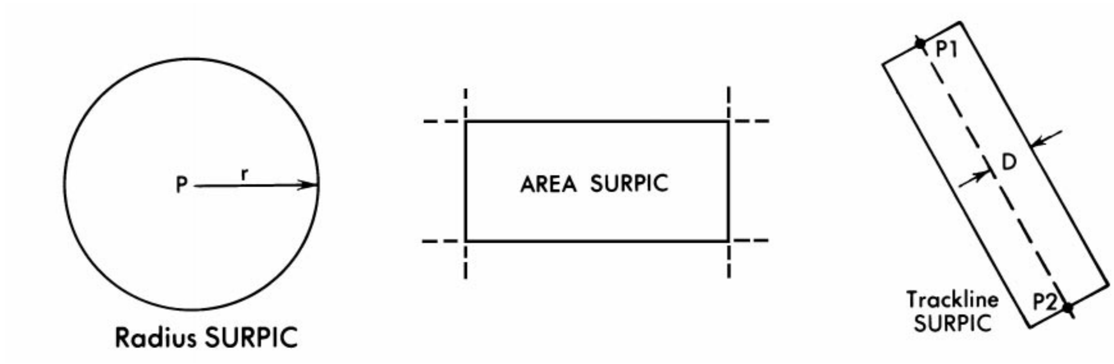


Figure 2906a. Radius SURPIC, Area SURPIC, and Trackine SURPIC.

The **Area SURPIC** is obtained by specifying the date, time, and two latitudes and two longitudes. The controller can limit the ships to be listed as with the Radius SURPIC. There is no maximum or minimum size limitation on an Area SURPIC.

A sample Area SURPIC request is as follows:

"REQUEST 151300Z AREA SURPIC OF WEST-BOUND SHIPS FROM 43N TO 31N LATITUDE AND FROM 130W TO 150W LONGITUDE FOR SHIP DISTRESS M/V EVENING SUN LOCATION 37N, 140W."

The **Trackline SURPIC** is obtained by specifying the date and time, two points (P1 and P2), whether the trackline should be rhumb line or great circle, what the half-width (D) coverage should be (in nautical miles), and whether all ships are desired (or only doctor ships, or just those east or west-bound). The half-width (D) specified should not exceed 100 miles. When received, the SURPIC will list ships in order from P1 to P2. There is no maximum or minimum distance between P1 and P2.

A sample Trackline SURPIC request is as follows:

"REQUEST 310100Z GREAT CIRCLE TRACKLINE SURPIC OF ALL SHIPS WITHIN 50 MILES OF A LINE FROM 20.1N 150.2W TO 21.5N 158.0W FOR AIRCRAFT PRECAUTION."

A **Location Vessel** is used to determine the location of a specific ship. It permits a controller to determine the DR position of an AMVER participant wherever located.

A sample Location Vessel request is as follows:

"REQUEST PRESENT POSITION, COURSE, AND SPEED OF M/V POLARIS"

A Radius SURPIC as it would be received by a rescue center, listing all ships within a 200-mile radius of 26.2N, 179.9W, is shown in figure 2906b.

2907. Uses Of AMVER Plot Information

An example of the use of a Radius SURPIC is depicted in Figure 2907. In this situation rescue authorities believe that a ship in distress, or her survivors, will be found in the rectangular area. The Rescue Coordination Center requests a listing of all eastbound ships within 100 miles of a carefully chosen position. Once this list is received by the Rescue Coordination Center a few moments later, messages can be prepared for satellite transmission to each vessel, or arrangements made to contact them by radio.

Each ship contacted may be asked to sail a rhumb line between two specified points, one at the beginning of the search area and one at the end. By carefully assigning ships to areas of needed coverage, very little time need be lost from the sailing schedule of each cooperating ship. Those ships joining the search would report their positions every few hours to the Rescue Coordination Center, together with weather data and any significant sightings. In order to achieve saturation coverage, a westbound SURPIC at the

Name	*Call sign*	Position	Course	Speed	SAR data	*Destination and ETA*	
CHILE MARU	JAYU	26.2 N 179.9E	C294	12.5K	H 1 6 R T X Z	KOBE	11
CPA 258 DEG. 012 MI. 032000Z							
WILYAMA	LKBD	24.8N 179.1W	C106	14.0K	H X R T V X Z	BALBOA	21
CPA 152 DEG. 092 MI. 032000Z							
PRES CLEVELAND	WITM	25.5N 177.0W	C284	19.3K	H 2 4 R D T X Z S	YKHAMA	08
CPA 265 WILL PASS WITHIN 10 MI 040430Z							
AENEAS	GMRT	25.9N 176.9E	C285	16.0K	H 8 R N V X Z	YKHAMA	10
CPA 265 DEG. 175 MI. 03200Z							

Figure 2906b. Radius SURPIC as received by a rescue center.

eastern extremity of the search area would also be used.

The Trackline SURPIC is most commonly used as a precautionary measure for aircraft. Rarely, if ever, is a major airliner forced to ditch at sea anymore. But occasions sometimes arise where a plane loses of one or more of its engines. A Trackline SURPIC, provided from the point of difficulty to the destination, provides the pilot with the added assurance of knowing the positions of vessels beneath him and that they have been alerted. SURPIC's have been used successfully to save the lives of pilots of small aircraft.

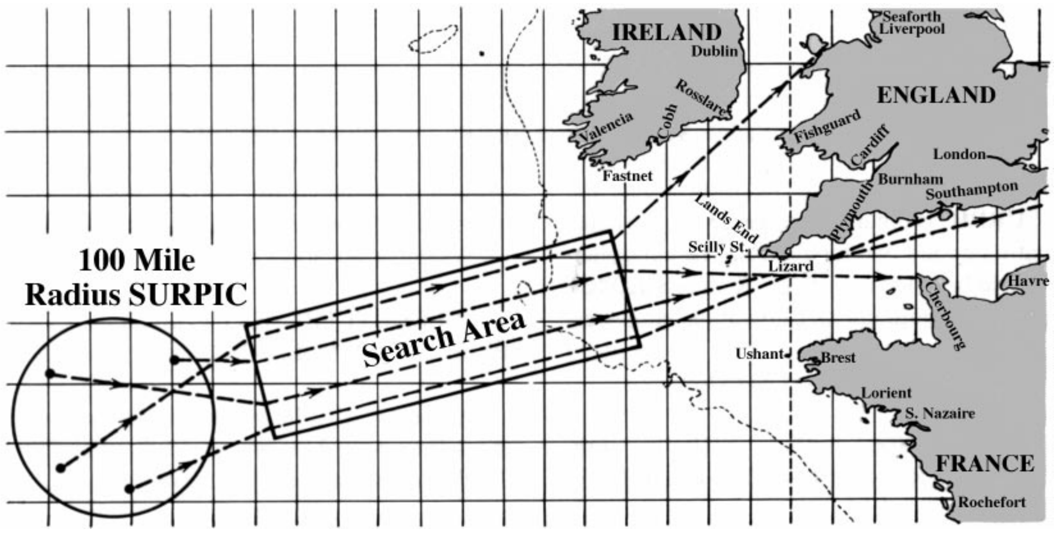


Figure 2907. Use of radius SURPIC.

EMERGENCY POSITION INDICATING RADIOBEACONS (EPIRB'S)

2908. Description And Capabilities

Emergency Position Indicating Radiobeacons (EPIRB's), devices which cost from $200 to over $1500, are designed to save lives by automatically alerting rescue authorities and indicating the distress location. EPIRB types are described below:

121.5/243 MHz EPIRB's (Class A, B, S): These are the most common and least expensive type of EPIRB, designed to be detected by overflying commercial or military aircraft. Satellites were designed to detect these EPIRB's but are limited for the following reasons:

1. Satellite detection range is limited for these EPIRB's (satellites must be within line of sight of both the EPIRB and a ground terminal for detection to occur).
2. EPIRB design and frequency congestion cause them to be subject to a high false alert/false alarm rate (over 99%); consequently, confirmation is re-

Type	Frequency	Description
Class A	121.5/243 MHz	Float-free, automatic activating, detectable by aircraft and satellite. Coverage limited (see Figure 2908).
Class B	121.5/243 MHz	Manually activated version of Class A.
Class C	VHF Ch. 15/16	Manually activated, operates on maritime channels only. Not detectable by satellite.
Class S	121.5/243 MHz	Similar to Class B, except that it floats, or is an integral part of a survival craft.
Category I	121.5/406 MHz	Float-free, automatically activated. Detectable by satellite anywhere in the world.
Category II	121.5/406 MHz	Similar to Category I, except manually activated.

Figure 2908a. EPIRB classifications.

Feature	*121.5/406 MHz EPIRB*	*121.5/243 MHz EPIRB*
Frequencies	406.025 MHz (locating) 121.500 MHz (homing)	121.500 MHz (civilian) 243.000 MHz (military)
Primary Function	Satellite alerting, locating, identification of distressed vessels.	Transmission of distress signal to passing aircraft and ships.
Distress Confirmation	Positive identification of coded beacon; each beacon signal is a coded, unique signal with registration data (vessel name, description, and telephone number ashore, assisting in confirmation).	Virtually impossible; no coded information, beacons often incompatible with satellites; impossible to know if signals are from EPIRB, ELT, or non-beacon source.
Signal	Pulse digital, providing accurate beacon location and vital information on distressed vessel.	Continuous signal allows satellite locating at reduced accuracy; close range homing.
Signal Quality	Excellent; exclusive use of 406 MHz for distress beacons; no problems with false alerts from non-beacon sources.	Relatively poor; high number of false alarms caused by other transmitters in the 121.5 MHz band.
Satellite Coverage	Global coverage, worldwide detection; satellite retains beacon data until next earth station comes into view.	Both beacon and LUT must be within coverage of satellite; detection limited to line of sight.
Operational Time	48 hrs. at -20°C.	48 hrs. at -20°C.
Output Power	5 watts at 406 MHz, .025 watts at 121.5 MHz.	0.1 watts average.
Strobe Light	High intensity strobe helps in visually locating search target.	None.
Location Accuracy (Search Area) and Time Required	1 to 3 miles (10.8 sq. miles); accurate position on first satellite overflight enables rapid SAR response, often within 30 min.	10 to 20 miles (486 sq. miles); SAR forces must wait for second system alert to determine final position before responding (1 to 3 hr. delay).

Figure 2908b. Summary comparison of 121.5/406 MHz and 121.5/243 MHz EPIRB's.

quired before SAR forces can be deployed;

3. EPIRB's manufactured before October 1988 may have design or construction problems (e.g. some models will leak and cease operating when immersed in water) or may not be detectable by satellite.

Class C EPIRB's: These are manually activated devices intended for pleasure craft which do not venture far offshore, and for vessels on the Great Lakes. They transmit a short burst on VHF-FM 156.8 MHz (Ch. 16) and a longer homing signal on 156.75 MHz (Ch. 15). Their usefulness depends upon a coast station or another vessel guarding channel 16 and recognizing the brief, recurring tone as an EPIRB. Class C EPIRB's are not recognized outside of the United States. Class C EPIRB's cannot be manufactured or sold in the United States after February 1995. Class C EPIRB's installed on board vessel's prior to February 1995 may be utilized until 1 February 1999 and not thereafter.

406 MHz EPIRB's (Category I, II): The 406 MHz EPIRB was designed to operate with satellites. Its signal allows a satellite local user terminal to locate the EPIRB (much more accurately than 121.5/243 MHz devices) and identify the vessel (the signal is encoded with the vessel's identity) anywhere in the world. There is no range limitation. These devices also include a 121.5 MHz homing signal, allowing aircraft and rescue vessels to quickly find the vessel in distress. These are the only type of EPIRB which must be tested by Coast Guard-approved independent laboratories before they can be sold for use within the United States.

An automatically activated, float-free version of this EPIRB has been required on SOLAS vessels (cargo ships over 300 tons and passenger ships on international voyages) since 1 August 1993. The Coast Guard requires U.S. commercial fishing vessels to carry this device (unless they carry a Class A EPIRB), and will require the same for other U.S. commercial uninspected vessels which travel more than 3 miles offshore.

Mariners should be aware of the differences between capabilities of 121.5/243 MHz and 121.5/406 MHz EPIRB's, as they have implications for alerting and locating of distress sites, as well as response by SAR forces. The advantages of 121.5/406 MHz devices are substantial, and are further enhanced by EPIRB-transmitted registration data on the carrying vessel. Owners of 121.5/406 MHz EPIRB's furnish registration information about their vessel, survival gear, and emergency points of contact ashore, all of which greatly enhance the response. The database for U.S. vessels is maintained by the National Oceanographic and Atmospheric Administration, and is accessed worldwide by SAR authorities to facilitate SAR response.

2909. Testing EPIRB's

EPIRB owners should periodically check for water tightness, battery expiration date, and signal presence. FCC rules allow Class A, B, and S EPIRB's to be turned on briefly (for three audio sweeps, or 1 second only) during the first 5 minutes of any hour. Signal presence can be detected by an FM radio tuned to 99.5 MHz, or an AM radio tuned to any vacant frequency and located close to an EPIRB. FCC rules allow Class C EPIRB's to be tested within the first 5 minutes of any hour, for not more than 10 seconds. Class C EPIRB's can be detected by a marine radio tuned to channel 15 or 16. All 121.5/406 MHz EPIRB's have a self-test function that should be used in accordance with manufacturers' instructions at least monthly.

2910. The COSPAS/SARSAT System

COSPAS is a Russian acronym for "Space System for Search of Distressed Vessels"; SARSAT signifies "Search And Rescue Satellite-Aided Tracking." COSPAS-SARSAT is an international satellite-based search and rescue system established by the U.S., Russia, Canada, and France to locate emergency radiobeacons transmitting on the frequencies 121.5, 243, and 406 MHz. Since its inception, the COSPAS-SARSAT system (SARSAT satellite only) has contributed to saving over 3000 lives.

The USCG receives data from MRCC stations and SAR Points of Contact (SPOC). See Figure 2910.

2911. Operation Of The COSPAS/SARSAT System

If an EPIRB is activated, COSPAS/SARSAT picks up the signal, locates the source and passes the information to a land station. From there, the information is relayed, either via coast radio or satellite, to Rescue Coordination Centers, rescue vessels and nearby ships. This constitutes a one-way only communications system, from the EPIRB via the satellite to the rescuers. It employs low altitude, near polar orbiting satellites and by exploiting the Doppler principle, locates the transmitting EPIRB within about two miles. Due to the low polar orbit, there may by a delay in receiving the distress message unless the footprint of the satellite is simultaneously in view with a monitoring station. However, unlike SafetyNET, worldwide coverage is provided.

As a satellite approaches a transmitting EPIRB, the frequency of the signals it receives is higher than that being transmitted; when the satellite has passed the EPIRB, the received frequency is lower. This creates a notable Doppler shift. Calculations which take into account the earth's rotation and other factors then determine the location of the EPIRB.

Country	*Location*	*Designator*	*Status*
Australia	Canberra	AUMCC	In Operation
Brazil	San Paulo	BBMCC	Under Test
Canada	Trenton	CMCC	In Operation
Chile	Santiago	CHMCC	Under Test
France	Toulouse	FMCC	In Operation
Hong Kong	Hong Kong	HKMCC	In Operation
India	Bangalore	INMCC	In Operation
Indonesia	Jakarta	IONCC	Under Test
ITDC	Taipei	TAMCC	TBD
Japan	Tokyo	JAMCC	In Operation
New Zealand			In Operation
Norway	Bodo	NMCC	In Operation
Pakistan	Lahore	PAMCC	—
Singapore	Singapore	SIMCC	—
Spain	Maspalomas	SPMCC	In Operation
Russian Federation	Moscow	CMC	In Operation
United Kingdom	Plymouth	UKMCC	In Operation
United States	Suitland	USMCC	In Operation

Figure 2910. Participants in COSPAS/SARSAT system.

The 406 MHz EPIRB’s incorporate an identification code. Once the satellite receives the beacon’s signals, the Doppler shift is measured and the beacon’s digital data is recovered from the signal. The information is time-lagged, formatted as digital data and transferred to the repeater downlink for real time transmission to any local user terminal. The digital data coded into each 406 MHz EPIRB’s memory provides distress information to SAR authorities for more rapid and efficient rescue. The data includes a maritime identification digit (MID, a 3 digit number identifying the administrative country) and either a ship station identifier (SSI, a 6 digit number assigned to specific ships), a ship radio call sign or a serial number to identify the ship in distress.

With the INMARSAT E satellite EPIRB’s, coverage does not extend to very high latitudes, but within the coverage area the satellite connection is instantaneous. However, to establish the EPIRB’s position, an interface with a GPS receiver or other sensor is needed.

2912. Alarm, Warning, And Alerting Signals

For MF (i.e. 2182 kHz), the EPIRB signal consists of either (1) a keyed emission modulated by a tone of 1280 Hz to 1320 Hz with alternating periods of emission and silence of 1 to 1.2 seconds each; or (2) the radiotelephone alarm signal followed by Morse code B (— • • •) and/or the call sign of the transmitting ship, sent by keying a carrier modulated by a tone of 1300 Hz or 2200 Hz. For VHF (i.e. 121.5 MHz and 243 MHz), the signal characteristics are in accordance with the specifications of Appendix 37A of the ITU Radio Regulations. For 156.525 MHz and UHF (i.e. 406 MHz to 406.1 MHz and 1645.5 MHz to 1646.5 MHz), the signal characteristics are in accordance with CCIR recommendations.

The purpose of these signals is to help determine the position of survivors for SAR operations. They indicate that one or more persons are in distress, may no longer be aboard a ship or aircraft, and may not have a receiver available.

Any vessel or aircraft receiving an EPIRB signal while no distress or urgent traffic is being passed shall initiate a distress message on the assumption that the EPIRB sending station is unable to transmit a distress message. The keying cycles for MF EPIRB’s may be interrupted for speech transmission.

CHAPTER 30

HYDROGRAPHY AND HYDROGRAPHIC REPORTS

3000. Introduction

Because the nautical chart is so essential to safe navigation, it is important for the mariner to understand the capabilities and limitations of both digital and paper charts. Previous chapters have dealt with horizontal and vertical datums, chart projections, and other elements of cartographic science. This chapter will explain some basic concepts of hydrography and cartography which are important to the navigator, both as a user and as a source of data. **Hydrography** is the science of measurement and description of all of the factors which affect navigation, including depths, shorelines, tides, currents, magnetism, and other factors. **Cartography** is the final step in a long process which leads from raw data to a usable chart for the mariner.

The mariner, in addition to being the primary user of hydrographic data, is also an important source of data used in the production and correction of nautical charts. This chapter discusses the processes involved in producing a nautical chart, whether in digital or paper form, from the initial planning of a hydrographic survey to the final printing. With this information, the mariner can better evaluate the information which comes to his attention and can forward it in a form that will be most useful to charting agencies, allowing them to produce more accurate and useful charts.

BASICS OF HYDROGRAPHIC SURVEYING

3001. Planning The Survey

The basic documents used to produce nautical charts are hydrographic surveys. Much additional information is included, but the survey is central to the compilation of a chart. A survey begins long before actual data collection starts. Some elements which must be decided are:

- Exact area of the survey.
- Type of survey (reconnaissance or standard) and scale to meet standards of chart to be produced.
- Scope of the survey (short or long term).
- Platforms available (ships, launches, aircraft, leased vessels, cooperative agreements).
- Support work required (aerial or satellite photography, geodetics, tides).
- Limiting factors (budget, political or operational constraints, positioning systems limitations, logistics).

Once these issues are decided, all information available in the survey area is reviewed. This includes aerial photography, satellite data, topographic maps, existing nautical charts, geodetic information, tidal information, and anything else affecting the survey. The survey planners then compile sound velocity information, climatology, water clarity data, any past survey data, and information from lights lists, sailing directions, and notices to mariners. Tidal information is thoroughly reviewed and tide gauge locations chosen. Local vertical control data is reviewed to see if it meets the expected accuracy standards, so the tide gauges can be linked to the vertical datum used for the survey. Horizontal control is reviewed to check for accuracy and discrepancies and to determine sites for local positioning systems to be used in the survey.

Line spacing refers to the distance between tracks to be run by the survey vessel. It is chosen to provide the best coverage of the area using the equipment available. Line spacing is a function of the depth of water, the sound footprint of the collection equipment to be used, and the complexity of the bottom. Once line spacing is chosen, the hydrographer can compute the total miles of survey track to be run and have an idea of the time required for the survey, factoring in the expected weather and other possible delays. The scale of the survey, orientation to the shorelines in the area, and the method of positioning determine line spacing. Planned tracks are laid out so that there will be no gaps between sound lines and sufficient overlaps between individual survey areas.

Lines with spacing greater than the primary survey's line spacing are run at right angles to the primary survey development to verify data repeatability. These are called **cross check lines**.

Other tasks to be completed with the survey include bottom sampling, seabed coring, production of sonar pictures of the seabed, gravity and magnetic measurements (on deep ocean surveys), and sound velocity measurements in the water column.

3002. Echo Sounders In Hydrographic Surveying

Echo sounders were developed in the early 1920s, and compute the depth of water by measuring the time it takes for a pulse of sound to travel from the source to the sea bottom and return. A device called a **transducer** converts electrical energy into sound energy and vice versa. For basic hydrographic surveying, the transducer is mounted permanently in the bottom of the survey vessel, which then follows the planned trackline, generating soundings along the track.

The major difference between different types of echo sounders is in the frequencies they use. Transducers can be classified according to their beam width, frequency, and power rating. The sound radiates from the transducer in a cone, with about 50% actually reaching to sea bottom. **Beam width** is determined by the frequency of the pulse and the size of the transducer. In general, lower frequencies produce a wider beam, and at a given frequency, a smaller transducer will produce a wider beam. Lower frequencies also penetrate deeper into the water, but have less resolution in depth. Higher frequencies have greater resolution in depth, but less range, so the choice is a trade-off. Higher frequencies also require a smaller transducer. A typical low frequency transducer operates at 12 kHz and a high frequency one at 200 kHz.

The formula for depth determined by an echo sounder is:

$$D = \frac{V \times T}{2} + K + D_r$$

where D is depth from the water surface, V is the average velocity of sound in the water column, T is round-trip time for the pulse, K is the system index constant, and D_r is the depth of the transducer below the surface (which may not be the same as vessel draft). V, D_r, and T can be only generally determined, and K must be determined from periodic calibration. In addition, T depends on the distinctiveness of the echo, which may vary according to whether the sea bottom is hard or soft. V will vary according to the density of the water, which is determined by salinity, temperature, and pressure, and may vary both in terms of area and time. In practice, average sound velocity is usually measured on site and the same value used for an entire survey unless variations in water mass are expected. Such variations could occur, for example, in areas of major currents. While V is a vital factor in deep water surveys, it is normal practice to reflect the echo sounder signal off a plate suspended under the ship at typical depths for the survey areas in shallow waters. The K parameter, or index constant, refers to electrical or mechanical delays in the circuitry, and also contains any constant correction due to the change in sound velocity between the upper layers of water and the average used for the whole project. Further, vessel speed is factored in and corrections are computed for settlement and squat, which affect transducer depth. Vessel roll, pitch, and heave are also accounted for. Finally, the observed tidal data is recorded in order to correct the soundings during processing.

Tides are accurately measured during the entire survey so that all soundings can be corrected for tide height and thus reduced to the chosen vertical datum. Tide corrections eliminate the effect of the tides on the charted waters and ensure that the soundings portrayed on the chart are the minimum available to the mariner at the sounding datum. Observed, not predicted, tides are used to account for both astronomically and meteorlogically induced water level changes during the survey.

3003. Collecting Survey Data

While sounding data is being collected along the planned tracklines by the survey vessel(s), a variety of other related activities are taking place. A large-scale **boat sheet** is produced with many thousands of individual soundings plotted. A complete navigation journal is kept of the survey vessel's position, course and speed. Side-scan sonar may be deployed to investigate individual features and identify rocks, wrecks, and other dangers. Time is the parameter which links the ship's position with the various echograms, sonograms, journals, and boat sheets that make up the hydrographic data package.

3004. Processing Hydrographic Data

During processing, echogram data and navigational data are combined with tidal data and vessel/equipment corrections to produce **reduced soundings**. This reduced data is combined on a plot of the vessel's actual track the boat sheet data to produce a **smooth sheet**. A contour overlay is usually made to test the logic of all the data shown. All anomolous depths are rechecked in either the survey records or in the field. If necessary, sonar data are then overlayed to analyze individual features as related to depths. It may take dozens of smooth sheets to cover the area of a complete survey. The smooth sheets are then ready for cartographers, who will choose representative soundings manually or using automated systems from thousands shown, to produce a nautical chart. Documentation of the process is such that any individual sounding on any chart can be traced back to its original uncorrected value. See Figure 3004.

3005. Recent Developments In Hydrographic Surveying

The evolution of echo sounders has followed the same pattern of technological innovation seen in other areas. In the 1940s low frequency/wide beam sounders were developed for ships to cover larger ocean areas in less time with some loss of resolution. Boats used smaller sounders which usually required visual monitoring of the depth. Later, narrow beam sounders gave ship systems better resolution using higher frequencies, but with a corresponding loss of area. These were then combined into dual-frequency systems. All echo sounders, however, used a single transducer, which limited surveys to single lines of soundings. For boat equipment, automatic recording became standard.

The last three decades have seen the development of multi-

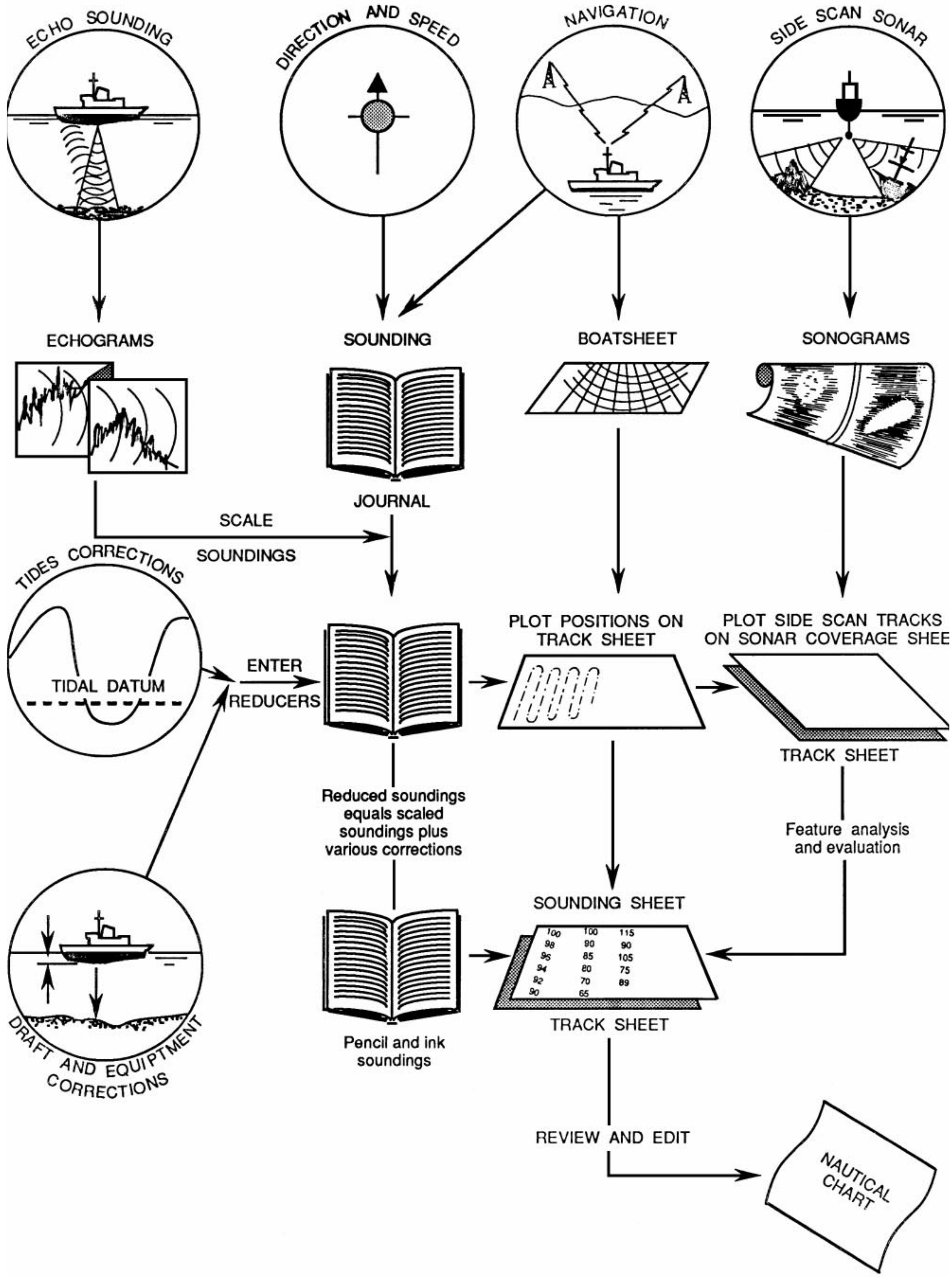


Figure 3004. The process of hydrographic surveying.

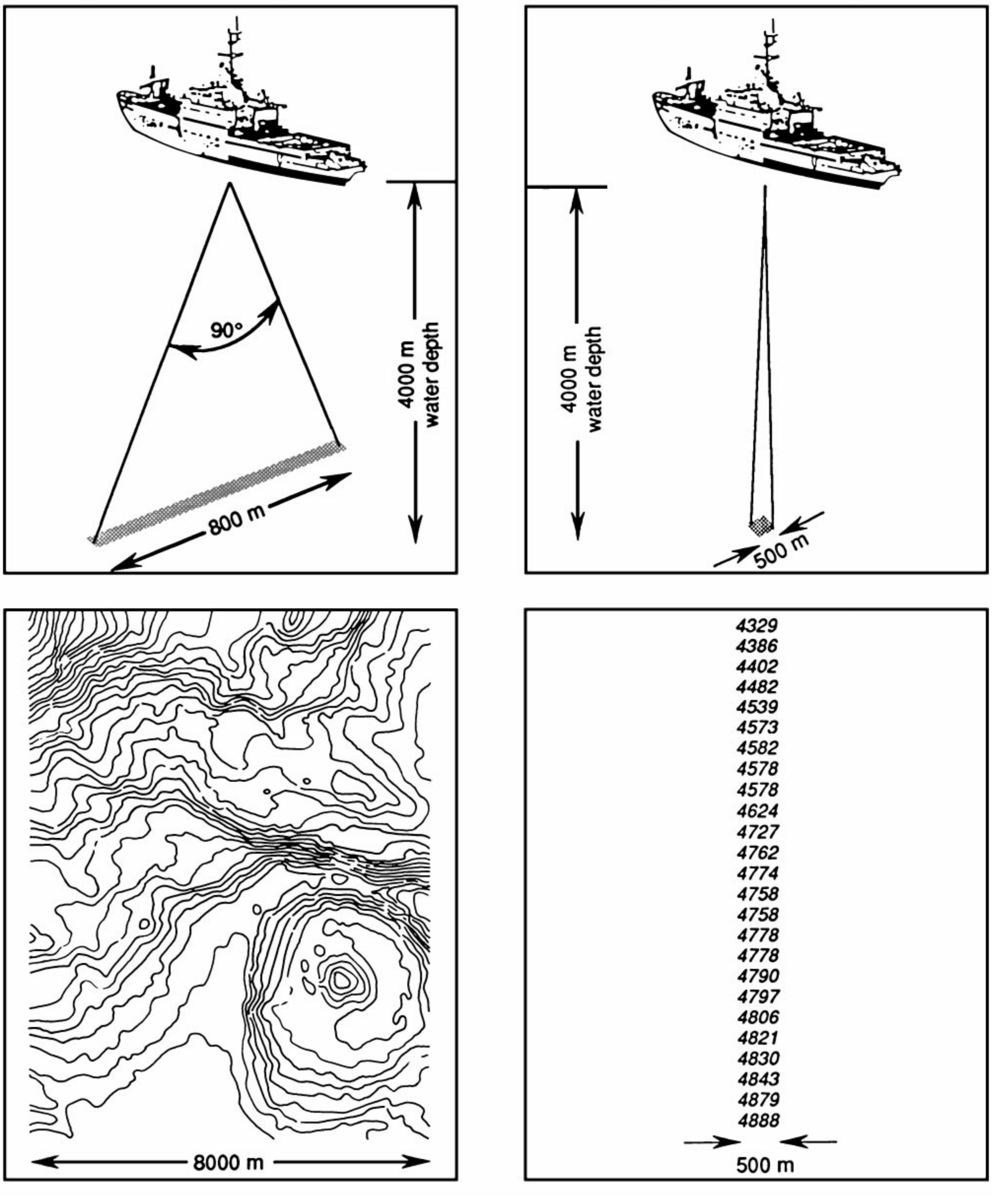


Figure 3005. Swath versus single-transducer surveys.

ple-transducer, multiple-frequency sounding systems which are able to scan a wide area of seabed. Two general types are in use. Open waters are best surveyed using an array of transducers spread out athwartships across the hull of the survey vessel. They may also be deployed from an array towed behind the vessel at some depth to eliminate corrections for vessel heave, roll, and pitch. Typically, as many as 16 separate transducers are arrayed, sweeping an arc of 90°. The area covered by these **swath survey systems** is thus a function of water depth. In shallow water, track lines must be much closer together than in deep water. This is fine with hydrographers, because shallow waters need more closely spaced data to provide an accurate portrayal of the bottom on charts. The second type of multiple beam system uses an array of vertical beam transducers rigged out on poles abeam the survey vessel with transducers spaced to give overlapping coverage for the general water depth. This is an excellent configuration for very shallow water, providing very densely spaced soundings from which an accurate picture of the bottom can be made for harbor and small craft charts. The width of the swath of this system is fixed by the distance between the two outermost transducers and is not dependent on water depth.

A recent development is **Airborne Laser Hydrography (ALH)**. An aircraft flies over the water, transmitting a laser beam. Part of the generated laser beam is reflected by the water's surface, which is noted by detectors. The rest penetrates to the sea bottom and is also partially reflected; this is also detected. Water depth can be computed from the difference in times of receipt of the two reflected pulses. Two different wavelength beams can also be used, one which reflects off the surface of the water, and one which penetrates and is reflected off the sea bottom. The obvious limitation of this system is water clarity. However, no other system can survey at 200 or so miles per hour while operating directly over shoals, rocks, reefs, and other hazards to boats. Both polar and many tropical waters are suitable for ALH systems. Depth readings up to 40 meters have been made, and at certain times of the year, some 80% of the world's coastal waters are estimated to be clear enough for ALH.

HYDROGRAPHIC REPORTS

3006. Chart Accuracies

The chart results from a hydrographic survey can be no more accurate than the survey; the survey's accuracy, in turn, is limited by the positioning system used. For many older charts, the positioning system controlling data collection involved using two sextants to measure horizontal angles between signals established ashore. The accuracy of this method, and to a lesser extent the accuracy of modern, shore based electronic positioning methods, deteriorates rapidly with distance. This often determined the maximum scale which could be considered for the final chart. With the advent of the Global Positioning System (GPS) and the establishment of Differential GPS networks, the mariner can now navigate with greater accuracy than could the hydrographic surveyor who collected the chart source data. Therefore, exercise care not to take shoal areas or other hazards closer aboard than was past practice because they may not be exactly where charted. This is in addition to the caution the mariner must exercise to be sure that his navigation system and chart are on the same datum. The potential danger to the mariner increases with digital charts because by zooming in, he can increase the chart scale beyond what can be supported by the source data. The constant and automatic update of the vessels position on the chart display can give the navigator a false sense of security, causing him to rely on the accuracy of a chart when the source data from which the chart was compiled cannot support the scale of the chart displayed.

3007. Navigational And Oceanographic Information

Mariners at sea, because of their professional skills and location, represent a unique data collection capability unobtainable by any government agency. Provision of high quality navigational and oceanographic information by government agencies *requires* active participation by mariners in data collection and reporting. Examples of the type of information required are reports of obstructions, shoals or hazards to navigation, sea ice, soundings, currents, geophysical phenomena such as magnetic disturbances and subsurface volcanic eruptions, and marine pollution. In addition, detailed reports of harbor conditions and facilities in both busy and out-of-the-way ports and harbors helps charting agencies keep their products current. The responsibility for collecting hydrographic data by U.S. Naval vessels is detailed in various directives and instructions. Civilian mariners, because they often travel to a wider range of ports, also have an opportunity to contribute substantial amounts of information.

3008. Responsibility For Information

The Defense Mapping Agency, the U.S. Naval Oceanographic Office (NAVOCEANO), the U.S. Coast Guard and the Coast and Geodetic Survey (C&GS) are the primary agencies which receive, process, and disseminate marine information in the U.S.

DMA provides charts and chart update (*Notice to Mariners*) and other nautical materials for the U.S. military services and for navigators in general in waters outside the U.S.

NAVOCEANO conducts hydrographic and oceanographic surveys of primarily foreign or international waters, and disseminates information to naval forces, government agencies, and civilians.

The Coast and Geodetic Survey (C&GS) conducts hydrographic and oceanographic surveys and provides charts for marine and air navigation in the coastal zones of the United States and its territories.

The U.S. Coast Guard is charged with protecting safety of life and property at sea, maintaining aids to navigation,

and improving the quality of the marine environment. In the execution of these duties, the Coast Guard collects, analyzes, and disseminates navigational and oceanographic data.

Modern technology allows contemporary navigators to contribute to the body of hydrographic and oceanographic information.

Navigational reports are divided into four categories:

1. Safety Reports
2. Sounding Reports
3. Marine Data Reports
4. Port Information Reports

The seas and coastlines continually change through the actions of man and nature. Improvements realized over the years in the nautical products published by DMAHTC, NOS, and U.S. Coast Guard have been made possible largely by the reports and constructive criticism of seagoing observers, both naval and merchant marine. DMAHTC and NOS continue to rely to a great extent on the personal observations of those who have seen the changes and can compare charts and publications with actual conditions. In addition, many ocean areas and a significant portion of the world's coastal waters have never been adequately surveyed for the purpose of producing modern nautical charts.

Information from all sources is evaluated and used in the production and maintenance of DMAHTC, NOS and Coast Guard charts and publications. Information from surveys, while originally accurate, is subject to continual change. As it is impossible for any hydrographic office to conduct continuous worldwide surveys, reports of changing conditions depend on the mariner. Such reports provide a steady flow of valuable information from all parts of the globe.

After careful analysis of a report and comparison with all other data concerning the same area or subject, the organization receiving the information takes appropriate action. If the report is of sufficient urgency to affect the immediate safety of navigation, the information will be broadcast as a SafetyNET or NAVTEX message. Each report is compared with others and contributes in the compilation, construction, or correction of charts and publications. It is only through the constant flow of new information that charts and publications can be kept accurate and up-to-date.

A convenient Data Collection Kit is available free from DMAHTC and NOS sales agents and from DMAHTC Representatives. The stock number is HYDRODATAKIT.

3009. Safety Reports

Safety reports are those involving navigational safety which must be reported and disseminated by message. The types of dangers to navigation which will be discussed in this section include ice, floating derelicts, wrecks, shoals, volcanic activity, mines, and other hazards to shipping.

1. Ice—Mariners encountering ice, icebergs, bergy bits, or growlers in the North Atlantic should report to Commander, International Ice Patrol, Groton, CT through a U.S. Coast Guard Communications Station. Direct printing radio teletype (SITOR) is available through USCG Communications Stations Boston or Portsmouth.

Satellite telephone calls may be made to the Ice Patroloffice in Groton, Connecticut throughout the season at (203) 441-2626 (Ice Patrol Duty Officer). Messages can also be sent through Coast Guard Operations Center, Boston at (617) 223-8555.

When sea ice is observed, the concentration, thickness, and position of the leading edge should be reported. The size, position, and, if observed, rate and direction of drift, along with the local weather and sea surface temperature, should be reported when icebergs, bergy bits, or growlers are encountered.

Ice sightings should also be included in the regular synoptic ship weather report, using the five-figure group following the indicator for ice. This will assure the widest distribution to all interested ships and persons. In addition, sea surface temperature and weather reports should be made to COMINTICEPAT every 6 hours by vessels within latitude 40°N and 52°N and longitude 38°W and 58°W, if a routine weather report is not made to METEO Washington.

2. Floating Derelicts—All observed floating and drifting dangers to navigation that could damage the hull or propellers of a vessel at sea should be immediately reported by radio. The report should include a brief description of the danger, the date, time (GMT) and the location (latitude and longitude).

3.Wrecks/Man-Made Obstructions—Information is needed to assure accurate charting of wrecks, man-made obstructions, other objects dangerous to surface and submerged navigation, and repeatable sonar contacts that may be of interest to the U.S. Navy. Man-made obstructions not in use or abandoned are particularly hazardous if unmarked and should be reported immediately. Examples include abandoned wellheads and pipelines, submerged platforms and pilings, and disused oil structures. Ship sinkings, strandings, disposals. or salvage data are also reportable, along with any large amounts of debris, particularly metallic.

Accuracy, especially in position, is vital: therefore, the date and time of the observation of the obstruction as well as the method used in establishing the position, and an estimate of the fix accuracy should be included. Reports should also include the depth of water, preferably measured by soundings (in fathoms or meters). If known, the name, tonnage, cargo, and cause of casualty should be provided.

Data concerning wrecks, man-made obstructions, other sunken objects, and any salvage work should be as complete as possible. Additional substantiating information is encouraged.

4. Shoals—When a vessel discovers an uncharted or erroneously charted shoal or an area that is dangerous to navigation, all essential details should be immediately reported to

DMAHTC WASHINGTON DC via radio. An uncharted depth of 300 fathoms or less is considered an urgent danger to submarine navigation. Immediately upon receipt of messages reporting dangers to navigation, DMAHTC issues appropriate NAVAREA warnings. The information must appear on published charts as "reported" until sufficient substantiating evidence (i.e. clear and properly annotated echograms and navigation logs, and any other supporting information) is received.

Therefore, originators of shoal reports are requested to verify and forward all substantiating evidence to DMAHTC at the earliest opportunity. It cannot be overemphasized that clear and properly annotated echograms and navigation logs are especially important in shoal reports.

5. Volcanic Activity—Volcanic disturbances may be observed from ships in many parts of the world. On occasion, volcanic eruptions may occur beneath the surface of the water. These submarine eruptions may occur more frequently and be more widespread than has been suspected in the past. Sometimes the only evidence of a submarine eruption is a noticeable discoloration of the water, a marked rise in sea surface temperature, or floating pumice. Mariners witnessing submarine activity have reported steams with a foul sulfurous odor rising from the sea surface, and strange sounds heard through the hull, including shocks resembling a sudden grounding. A subsea volcanic eruption may be accompanied by rumbling and hissing as hot lava meets the cold sea.

In some cases, reports of discolored water at the sea surface have been investigated and found to be the result of newly formed volcanic cones on the sea floor. These cones can grow rapidly (within a few years) to constitute a hazardous shoal.

It is imperative that a mariner report evidence of volcanic activity immediately to DMAHTC by message. Additional substantiating information is encouraged.

6. **Mines**—All mines or objects resembling mines should be considered armed and dangerous. An immediate radio report to DMAHTC should include (if possible):

1. Greenwich Mean Time and date.
2. Position of mine, and how near it was approached.
3. Size, shape, color, condition of paint, and presence of marine growth.
4. Presence or absence of horns or rings.
5. Certainty of identification.

3010. Instructions For Safety Report Messages

The International Convention for the Safety of Life at Sea (1974), which is applicable to all U.S. flag ships, requires: "The master of every ship which meets with dangerous ice, dangerous derelict, or any other direct danger to navigation, or a tropical storm, or encounters subfreezing air temperatures associated with gale force winds causing severe ice accretion on superstructures, or winds of force 10 or above on the Beaufort scale for which no storm warning has been received, is bound to communicate the information by all means at his disposal to ships in the vicinity, and also to the competent authorities at the first point on the coast with which he can communicate."

The report should be broadcast first on 2182 kHz prefixed by the safety signal "SECURITE." This should be followed by transmission of the message on a suitable working frequency to the proper shore authorities. The transmission of information regarding ice, derelicts, tropical storms, or any other direct danger to navigation is obligatory. The form in which the information is sent is not obligatory. It may be transmitted either in plain language (preferably English) or by any means of International Code of Signals (wireless telegraphy section). It should be issued CQ to all ships and should also be sent to the first station with which communication can be made with the request that it be transmitted to the appropriate authority. A vessel will not be charged for radio messages to government authorities reporting dangers to navigation.

Each radio report of a danger to navigation should answer briefly three questions:

1. What? A description to of the object or phenomenon.
2. Where? Latitude and longitude.
3. When? Greenwich Mean Time (GMT) and date.

Examples:

Ice

SECURITE. ICE: LARGE BERG SIGHTED DRIFTING SW AT .5 KT 4605N, 4410W, AT 0800 GMT, MAY 15.

Derelicts

SECURITE. DERELICT: OBSERVED WOODEN 25 METER DERELICT ALMOST SUBMERGED AT 4406N, 1243W AT 1530 GMT, APRIL 21.

The report should be addressed to one of the following shore authorities as appropriate:

1. U.S. Inland Waters—Commander of the Local Coast Guard District.
2. Outside U.S. Waters—DMAHTC WASHINGTON, DC.

Whenever possible, messages should be transmitted via the nearest government radio station. If it is impractical to use a government station, a commercial station may be used. U.S. government navigational warning messages should invariably be sent through U.S. radio stations, government or commercial, and never through foreign stations.

Detailed instructions for reporting via radio are contained in DMAHTC *Pub. 117, Radio Navigation Aids.*

OCEANIC SOUNDING REPORTS

3011. Sounding Reports

Acquisition of reliable sounding data from all ocean areas of the world is a continuing effort of DMAHTC, NAVOCEANO, and NOS. There are vast ocean areas where few soundings have ever been acquired. Much of the bathymetric data shown on charts has been compiled from information submitted by mariners. Continued cooperation in observing and submitting sounding data is absolutely necessary to enable the compilation of accurate charts. Compliance with sounding data collection procedures by merchant ships is voluntary, but for U.S. Naval vessels compliance is required under various fleet directives.

3012. Areas Where Soundings Are Needed

Prior to a voyage, navigators can determine the importance of recording sounding data by checking the charts for the route. Any ship crossing a densely sounded shipping lane perpendicular or nearly perpendicular to the lane can obtain very useful sounding data despite the density. Such tracks provide cross checks for verifying existing data. Other indications that soundings may be particularly useful are:

1. Old sources listed on source diagram or source note on chart.
2. Absence of soundings in large areas.
3. Presence of soundings, but only along well-defined lines indicating the track of the sounding vessel, with few or no sounding between tracks.
4. Legends such as “Unexplored area.”

3013. Fix Accuracy

A realistic goal of open ocean positioning for sounding reports is ±1 nautical mile with the continuous use of GPS. However, depths of 300 fathoms or less should always be reported regardless of the fix accuracy. When such depths are uncharted or erroneously charted, they should be reported by message to DMAHTC WASHINGTON DC, giving the best available positioning accuracy. Echograms and other supporting information should then be forwarded by mail to DMAHTC.

The accuracy goal noted above has been established to enable DMAHTC to create a high quality data base which will support the compilation of accurate nautical charts. It is particularly important that reports contain the navigator’s best estimate of his fix accuracy and that the positioning aids being used (GPS, Loran C, etc.) be identified.

3014. False Shoals

Many poorly identified shoals and banks shown on charts are probably based on encounters with the **Deep Scattering Layer (DSL)**, ambient noise, or, on rare occasions, submarine earthquakes. While each appears real enough at the time of its occurrence, a knowledge of the events that normally accompany these incidents may prevent erroneous data from becoming a charted feature.

The DSL is found in most parts of the world. It consists of a concentration of marine life which descends from near the surface at sunrise to an approximate depth of 200 fathoms during the day. It returns near the surface at sunset. Although at times the DSL may be so concentrated that it will completely mask the bottom, usually the bottom return can be identified at its normal depth at the same time the DSL is being recorded.

Ambient noise or interference from other sources can cause erroneous data. This interference may come from equipment on board the ship, from another transducer being operated close by, or from waterborne noise. Most of these returns can be readily identified on the echo sounder records and should cause no major problems; however, on occasion they may be so strong and consistent as to appear as the true bottom.

Finally, a volcanic disturbance beneath the ship or in the immediate vicinity may give erroneous indications of a shoal. The experience has at times been described as similar to running aground or striking a submerged object. Regardless of whether the feature is an actual shoal or a submarine eruption the positions, date/time, and other information should be promptly reported to DMAHTC.

3015. Doubtful Hydrographic Data

Navigators are strongly requested to assist with the confirmation and proper charting of actual shoals and the removal from the charts of doubtful data which was erroneously reported.

The classification or confidence level assigned to doubtful hydrographic data is indicated by the following standard symbols:

Abbreviation	*Meaning*
Rep (date)	Reported (year)
E.D.	Existence Doubtful
P.A.	Position Approximate
P.D.	Position Doubtful

Many of these reported features are sufficiently deep that if valid, a ship can safely navigate across the area. Confirmation of the existence of the feature will result in proper charting. On the other hand, properly collected and annotated sounding reports of the area may enable DMAHTC to accumulate sufficient evidence to justify the removal of the sounding from the chart.

3016. Preparation Of Sounding Reports

The procedures for preparing sounding reports have been designed to minimize the efforts of the shipboard observers, yet provide the essential information needed by DMAHTC. Blank OCEANIC SOUNDING REPORT forms are available from DMAHTC as a stock item or through DMA Representatives in Los Angeles/Long Beach, New Orleans, and Washington, D.C. Submission of plotted sounding tracks is not required. Annotated echograms and navigation logs are preferred. The procedure for collecting sounding reports is for the ship to operate a recording echo sounder while transiting an area where soundings are desired. Fixes and course changes are recorded in the log, and the event marker is used to note these events on the echogram. Both the log and echogram can then be sent to DMAHTC whenever convenient.

The following annotations or information should be clearly written on the echogram to ensure maximum use of the recorded depths:

1. **Ship's name**—At the beginning and end of each roll of echogram or portion.
2. **Date**—Annotated at 1200 hours each day and when starting and stopping the echo sounder, or at least once per roll.
3. **Time**—The echogram should be annotated at the beginning of the sounding run, at least once each hour thereafter, at every scale change, and at all breaks in the echogram record. Accuracy of these time marks is critical for correlation with ship's position.
4. **Time Zone**—Greenwich Mean Time (GMT) should be used if practicable. In the event local zone times are used, annotate echogram whenever clocks are reset and identify zone time in use. It is most important that the echogram and navigation log use the same time basis.

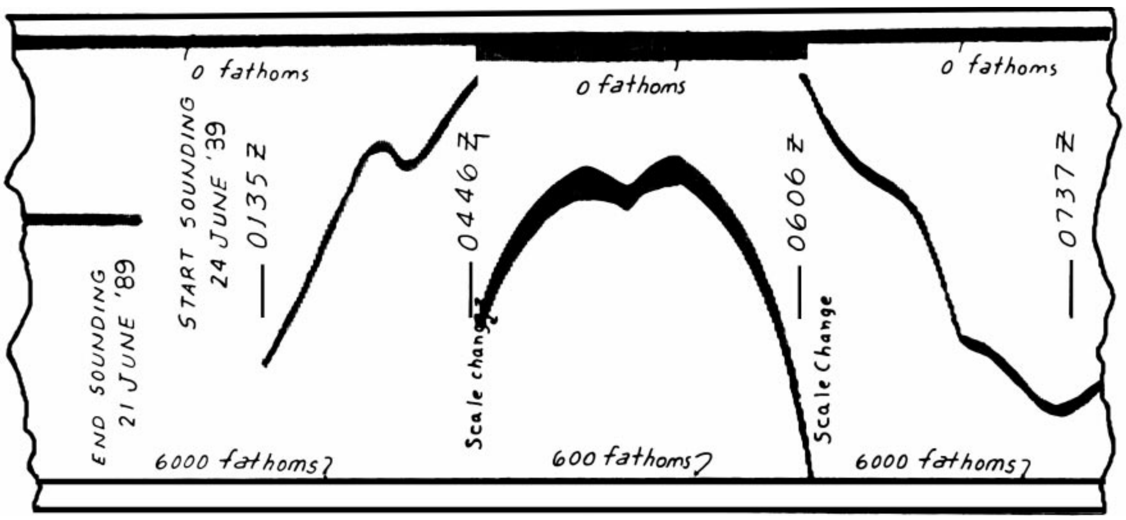


Figure 3016a. Properly annotated echo sounding record.

NAVIGATION LOG							REMARKS
DATE	TIME (GMT)	LAT.	LONG.	NAV. FIX	COURSE	SPEED	
11/2/83	0221	29°41'N	124°10'E	LORAN	093°	12.3	
	0340				097°	12.3	CHANGE COURSE
	0400	29°40'N	124°35'E	NOON FIX	097°	12.3	
	0728	29°35'N	125°22'E	LORAN	097°	12.3	
	0810				VARIOUS	8.2	REDUCE SPEED – MANUVERING TO AVOID FISHING BOATS
	0826	29°34'N	125°35.5'E	LORAN	097°	12.3	RESUME COURSE AND SPEED
	1011	29°32'N	125°56'E	EVENING STARS	097°	12.3	
	1620	29°23'N	127°22'E	LORAN	102°	12.4	CHANGE COURSE
	2230	29°06.2'N	128°48.5'E	RADAR STAR	102°	12.5	
	2305				102°	10.1	REDUCE SPEED

Figure 3016b. Typical navigation log for hydrographic reporting.

5. **Phase or scale changes**—If echosounder does not indicate scale setting on echogram automatically, clearly label all depth phase (or depth scale) changes and the exact time they occur. Annotate the upper and lower limits of the echogram if necessary.

Figure 3016a and Figure 3016b illustrates the data necessary to reconstruct a sounding track. If ship operations dictate that only periodic single ping soundings can be obtained, the depths may be recorded in the Remarks column. A properly annotated echogram is always strongly preferred by DMAHTC over single ping soundings whenever operations permit. The navigation log is vital to the reconstruction of a sounding track. Without the position information from the log, the echogram is virtually useless.

The data received from these reports is digitized and becomes part of the digital bathymetric data library of DMAHTC. This library is used as the basis of new chart compilation. Even in areas where numerous soundings already exist, sounding reports allow valuable cross-checking to verify existing data and more accurately portray the sea floor. This is helpful to our Naval forces and particularly to the submarine fleet, but is also useful to geologists, geophysicists, and other scientific disciplines.

A report of oceanic soundings should contain the following:

1. A completed Oceanic Sounding Report, Form DMAHTC 8053/1.
2. A detailed Navigation Log.
3. The echo sounding trace, properly annotated.

Each page of the report should be clearly marked with the ship's name and date, so that it can be identified if it becomes separated. Mail the report to:

Director
DMA Hydrographic/Topographic Center
MC, D-40
4600 Sangamore Rd.
Bethesda, MD, 20816-5003

OTHER HYDROGRAPHIC REPORTS

3017. Marine Information Reports

Marine Information Reports are reports of items of navigational interest such as the following:

1. Discrepancies in published information.
2. Changes in aids to navigation.
3. Electronic navigation reports.
4. Satellite navigation reports.
5. Radar navigation reports.
6. Magnetic disturbances.

Report any marine information which you believe may be useful to charting authorities or other mariners. Depending on the type of report, certain items of information are absolutely critical for a correct evaluation. The following general suggestions are offered to assist in reporting information that will be of maximum value:

1. The geographical position included in the report may be used to correct charts. Accordingly, it should be fixed by the most exact method available, more than one if possible.
2. If geographical coordinates are used to report position, they should be as exact as circumstances permit. Reference should be made to the chart by number, edition number, and date.
3. The report should state the method used to fix the position and an estimate of fix accuracy.
4. When reporting a position within sight of charted objects, the position may be expressed as bearings and ranges from them. Bearings should preferably be reported as true and expressed in degrees.
5. Always report the limiting bearings from the ship toward the light when describing the sectors in which a light is either visible or obscured. Although this is just the reverse of the form used to locate objects, it is the standard method used on DMAHTC nautical charts and in Light Lists.
6. A report prepared by one person should, if possible, be checked by another.

In most cases marine information can be adequately reported on one of the various forms printed by DMAHTC or NOS. It may be more convenient to annotate information directly on the affected chart and mail it to DMAHTC. As an example, it may be useful to sketch uncharted or erroneously charted shoals, buildings, or geological features directly on the chart. Appropriate supporting information should also be provided.

DMAHTC forwards reports applicable to NOS, NAVOCEANO, or Coast Guard products to the appropriate agency.

Reports by letter are just as acceptable as those prepared on regular forms. A letter report will often allow more flexibility in reporting details, conclusions, or recommendations concerning the observation. When reporting on the regular forms, if necessary use additional sheets to complete the details of an observation.

Reports are required concerning any errors in information

published on nautical charts or in nautical publications. The ports should be as accurate and complete as possible. This will result in corrections to the information including the issuance of Notice to Mariners changes when appropriate.

Report all changes, defects, establishment or discontinuance of navigational aids and the source of the information. Check your report against the light list, list of lights, Radio Aids to Navigation, and the largest scale chart of the area. If it is discovered that a new light has been established, report the light and its characteristics in a format similar to that carried in light lists and lists of lights. Forchanges and defects, report only elements that differ with light lists. If it is a lighted aid, identify by number. Defective aids to navigation in U.S. territorial waters should be reported immediately to the Commander of the local Coast Guard District.

3018. Electronic Navigation Reports

Electronic navigation systems such as GPS and LORAN have become an integral part of modern navigation. Reports on propagation anomalies or any unusual reception while using the electronic navigation system are desired.

Information should include:

1. Type of electronic navigation system and channel or frequency used.
2. Type of antenna: whip, vertical or horizontal wire.
3. Transmitting stations, rate or pair used.
4. Nature and description of the reception.
5. Type of signal match.
6. Date and time.
7. Position of own ship.
8. Manufacturer and model of receiver.

Calibration information is being collected in an effort to evaluate and improve the accuracy of the DMAHTC derived Loran signal propagation corrections incorporated in National Ocean Service Coastal Loran C charts. Loran C monitor data consisting of receiver readings with corresponding well defined reference positions are required. Mariners aboard vessels equipped with Loran C receiving units and having precise positioning capability independent of the Loran C system (i.e., docked locations or visual bearings, radar, GPS, Raydist, etc.) are requested to provide information to DMAHTC.

3019. Radar Navigation Reports

Reports of any unusual reception or anomalous propagation by radar systems caused by atmospheric conditions are especially desirable. Comments concerning the use of radar in piloting, with the locations and description of good radar targets, are particularly needed. Reports should include:

1. Type of radar, frequency, antenna height and type.
2. Manufacturer and model of the radar.
3. Date, time and duration of observed anomaly.
4. Position.
5. Weather and sea conditions.

Radar reception problems caused by atmospheric parameters are contained in four groups. In addition to the previously listed data, reports should include the following specific data for each group:

1. Unexplained echoes—Description of echo, apparent velocity and direction relative to the observer, and range.
2. Unusual clutter—Extent and Sector.
3. Extended detection ranges—Surface or airborne target, whether point or distributed target, such as a coastline or landmass.
4. Reduced detection ranges—Surface or airborne target, whether point or distributed target, such as a coastline or landmass.

3020. Magnetic Disturbances

Magnetic anomalies, the result of a variety of causes, exist in many parts of the world. DMAHTC maintains a record of such magnetic disturbances and whenever possible attempts to find an explanation. A better understanding of this phenomenon can result in more detailed charts which will be of greater value to the mariner.

The report of a magnetic disturbance should be as specific as possible, for instance: “Compass quickly swung 190° to 170°, remained offset for approximately 3 minutes and slowly returned.” Include position, ship’s course, speed, date, and time.

Whenever the readings of the standard magnetic compass are unusual, an azimuth check should be made as soon as possible and this information forwarded to DMAHTC.

PORT INFORMATION REPORTS

3021. Importance Of Port Information Reports

Port Information Reports provide essential information obtained during port visits which can be used to update and improve coastal, approach, and harbor charts as well as nautical publications including Sailing Directions, Coast Pilots, and Fleet Guides. Engineering drawings, hydrographic surveys and port plans showing new construction

affecting charts and publications are especially valuable.

Items involving navigation safety should be reported by message. Items which are not of immediate urgency, as well as additional supporting information may be submitted by the Port Information Report (DMAHTC Form 8330-1), or the Notice to Mariners Marine Information Report and Suggestion Sheet found in the back of each Notice to Mariners. Reports by letter are completely acceptable and may permit more reporting flexibility.

In some cases it may be more convenient and more effective to annotate information directly on a chart and mail it to DMAHTC. As an example, new construction, such as new port facilities, pier or breakwater modifications, etc., may be drawn on a chart in cases where a written report would be inadequate.

Specific Navy reporting requirements exist for ships visiting foreign ports. These reports are primarily intended to provide information for use in updating the Navy Port Directories. A copy of the navigation information resulting from port visits should be provided directly to DMAHTC by including DMAHTC WASHINGTON DC/MCC// as an INFO addressee on messages containing hydrographic information.

3022. What To Report

Coastal features and landmarks are almost constantly changing. What may at one time have been a major landmark may now be obscured by new construction, destroyed, or changed by the elements. Sailing Directions (Enroute) and Coast Pilots utilize a large number of photographs and line sketches. Photographs, particularly a series of overlapping views showing the coastline, landmarks, and harbor entrances are very useful. Photographs and negatives can be used directly as views or in the making of line sketches.

The following questions are suggested as a guide in preparing reports on coastal areas that are not included or that differ from the Sailing Directions and Coast Pilots.

Approach

1. What is the first landfall sighted?
2. Describe the value of soundings, radio bearings, GPS, LORAN, radar and other positioning systems in making a landfall and approaching the coast. Are depths, curves, and coastal dangers accurately charted?
3. Are prominent points, headlands, landmarks, and aids to navigation adequately described in Sailing Directions and Coast Pilots? Are they accurately charted?
4. Do land hazes, fog or local showers often obscure the prominent features of the coast?
5. Do discolored water and debris extend offshore? How far? Were tidal currents or rips experienced along the coasts or in approaches to rivers or bays?
6. Are any features of special value as radar targets?

Tides and Currents

1. Are the published tide and current tables accurate?
2. Does the tide have any special effect such as river bore? Is there a local phenomenon, such as double high or low water interrupted rise and fall?
3. Was any special information on tides obtained from local sources?
4. What is the set and drift of tidal currents along coasts, around headlands among islands, in coastal indentations?
5. Are tidal currents reversing or rotary? If rotary, do they rotate in a clockwise or counterclockwise direction?
6. Do subsurface currents affect the maneuvering of surface craft? If so, describe.
7. Are there any countercurrents, eddies, overfalls, or tide rips in the area? If so, locate.

River and Harbor Entrances

1. What is the depth of water over the bar, and is it subject to change? Was a particular stage of tide necessary to permit crossing the bar?
2. What is the least depth in the channel leading from sea to berth?
3. If the channel is dredged, when and to what depth and width? Is the channel subject to silting?
4. What is the maximum draft, length, and width of a vessel that can be taken into port?
5. If soundings were taken, what was the stage of tide? Were the soundings taken by echo sounder or lead line? If the depth information was received from other sources, what were they?
6. What was the date and time of water depth observations?

Hills, Mountains, and Peaks

1. Are hills and mountains conical, flat-topped, or of any particular shape?
2. At what range are they visible in clear weather?
3. Are they snowcapped throughout the year?
4. Are they cloud-covered at any particular time?
5. Are the summits and peaks adequately charted? Can accurate distances and/or bearings be obtained by sextant, pelorus, or radar?
6. What is the quality of the radar return?

Pilotage

1. Where is the signal station located?
2. Where does the pilot board the vessel? Are special arrangements necessary before a pilot boards?
3. Is pilotage compulsory? Is it advisable?
4. Will a pilot direct a ship in at night, during foul weather, or during periods of low visibility?

5. Where does the pilot boat usually lie?
6. Does the pilot boat change station during foul weather?
7. Describe the radiotelephone communication facilities available at the pilot station or pilot boat. What is the call-sign, frequency, and the language spoken?

General

1. What cautionary advice, additional data, and information on outstanding features should be given to a mariner entering the area for the first time?
2. At any time did a question or need for clarification arise while using DMAHTC, NOS, or Coast Guard products?
3. Were charted land contours useful while navigating using radar? Indicate the charts and their edition numbers.
4. Would it be useful to have radar targets or topographic features that aid in identification or position plotting described or portrayed in the Sailing Directions and Coast Pilots?

Photographs

The overlapping photograph method for panoramic views should be used. On the back of the photograph (negatives should accompany the required information), indicate the camera position by bearing and distance from a fixed, charted object if possible, name of the vessel, the date, time of exposure, and height of tide. All features of navigational value should be clearly and accurately identified on an overlay, if time permits. Bearings and distances (from the vessel) of uncharted features, identified on the print, should be included.

Radarscope Photography

Because of the value of radar as an aid to navigation, DMAHTC desires radarscope photographs. Guidelines for radar settings for radarscope photography are given in *Radar Navigation Manual, Pub. 1310*. Such photographs, reproduced in the Sailing Directions and Fleet Guides, supplement textual information concerning critical navigational areas and assist the navigator in correlating the radarscope presentation with the chart. To be of the greatest value, radarscope photographs should be taken at landfalls, sea buoys, harbor approaches, major turns in channels, constructed areas and other places where they will most aid the navigator. Two glossy prints of each photograph are needed. One should be unmarked, the other annotated.

Examples of desired photographs are images of fixed and floating navigational aids of various sizes and shapes as observed under different sea and weather conditions, and images of sea return and precipitation of various intensities. There should be two photographs of this type of image, one without the use of special anti clutter circuits and another showing remedial effects of these. Photographs of actual icebergs, growlers, and bergy bits under different sea conditions, correlated with photographs of their radarscope images are also desired.

Radarscope photographs should include the following annotations:

1. Wavelength.
2. Antenna height and rotation rate.
3. Range-scale setting and true bearing.
4. Antenna type (parabolic, slotted waveguide).
5. Weather and sea conditions, including tide.
6. Manufacturer's model identification.
7. Position at time of observation.
8. Identification of target by Light List, List of Lights, or chart.
9. Camera and exposure data.

Other desired annotations include:

1. Beam width between half-power points.
2. Pulse repetition rate.
3. Pulse duration (width).
4. Antenna aperture (width).
5. Peak power.
6. Polarization.
7. Settings of radar operating controls, particularly use of special circuits.
8. Characteristics of display (stabilized or unstabilized), diameter, etc.

Port Regulations and Restrictions

Sailing Directions (Planning Guides) are concerned with pratique, pilotage, signals, pertinent regulations, warning areas, and navigational aids. Updated and new information is constantly needed by DMAHTC. Port information is best reported on the prepared "Port Information Report", DMAHTC form 8330-1. If this form is not available, the following questions are suggested as a guide to the requested data.

1. Is this a port of entry for overseas vessels?
2. If not a port of entry where must vessel go for customs entry and pratique?
3. Where do customs, immigration, and health officials board?
4. What are the normal working hours of officials?
5. Will the officials board vessels after working hours? Are there overtime charges for after-hour services?
6. If the officials board a vessel underway, do they remain on board until the vessel is berthed?
7. Were there delays? If so, give details.
8. Were there any restrictions placed on the vessel?

9. Was a copy of the Port Regulations received from the local officials?
10. What verbal instructions were received from the local officials?
11. What preparations prior to arrival would expedite formalities?
12. Are there any unwritten requirements peculiar to the port?
13. What are the speed regulations?
14. What are the dangerous cargo regulations?
15. What are the flammable cargo and fueling regulations?.
16. Are there special restrictions on blowing tubes, pumping bilges. oil pollution, fire warps, etc.?
17. Are the restricted and anchorage areas correctly shown on charts, and described in the Sailing Directions and Coast Pilots?
18. What is the reason for the restricted areas; gunnery, aircraft operating, waste disposal, etc.?
19. Are there specific hours of restrictions, or are local blanket notices issued?
20. Is it permissible to pass through, but not anchor in, restricted areas?
21. Do fishing boats, stakes, nets, etc., restrict navigation?
22. What are the heights of overhead cables, bridges, and pipelines?
23. What are the locations of submarine cables, their landing points, and markers?
24. Are there ferry crossings or other areas of heavy local traffic?
25. What is the maximum draft, length, and breadth of a vessel that can enter?

Port Installations

Much of the port information which appears in the Sailing Directions and Coast Pilots is derived from visit reports and port brochures submitted by mariners. Comments and recommendations on entering ports are needed so that corrections to these publications can be made.

If extra copies of local port plans, diagrams, regulations, brochures, photographs, etc., can be obtained, send them to DMAHTC. It is not essential that they be printed in English. Local pilots, customs officials, company agents, etc., are usually good information sources.

Much of the following information is included in the regular Port Information Report, but may be used as a check-off list when submitting a letter report.

General

1. Name of the port.
2. Date of observation and report.
3. Name and type of vessel.
4. Gross tonnage.
5. Length (overall).
6. Breadth (extreme).
7. Draft (fore and aft).
8. Name of captain and observer.
9. U.S. mailing address for acknowledgment.

Tugs and Locks

1. Are tugs available or obligatory? What is their power?
2. If there are locks, what is the maximum size and draft of a vessel that can be locked through?

Cargo Handling Facilities

1. What are the capacities of the largest stationary, mobile, and floating cranes available? How was this information obtained?
2. What are the capacities, types, and number of lighters and barges available?
3. Is special cargo handling equipment available (e.g.) grain elevators, coal and ore loaders, fruit or sugar conveyors, etc.?
4. If cargo is handled from anchorage, what methods are used? Where is the cargo loaded? Are storage facilities available there?

Supplies

1. Are fuel oils, diesel oils, and lubricating oils available? If so, in what quantity?

Berths

1. What are the dimensions of the pier, wharf, or basin used?
2. What are the depths alongside? How were they obtained?
3. Describe berth/berths for working containers or roll-on/ roll-off cargo.
4. Does the port have berth for working deep draft tankers? If so, describe.
5. What storage facilities are available, both dry and refrigerated?
6. Are any unusual methods used when docking? Are special precautions necessary at berth?

Medical, Consular, and Other Services

1. Is there a hospital or the services of a doctor and dentist available?
2. Is there a United States consulate? Where is it located? If none, where is the nearest?

Anchorages

1. What are the limits of the anchorage areas?
2. In what areas is anchorage prohibited?
3. What is the depth, character of the bottom, types of holding ground, and swinging room avaiable?
4. What are the effects of weather, sea, swell, tides, currents on the anchorages?
5. Where is the special quarantine anchorage?
6. Are there any unusual anchorage restrictions?

Repairs and Salvage

1. What are the capacities of drydocks and marine railways, if available?
2. What repair facilities arc available? Are there repair facilities for electrical and electronic equipment?
3. Are divers and diving gear available?
4. Are there salvage tugs available? What is the size and operating radius?
5. Are any special services, (e.g., compass compensation or degaussing,) available?

MISCELLANEOUS HYDROGRAPHIC REPORTS

3023. Ocean Current Reports

The set and drift of ocean currents are of great concern to the navigator. Only with the correct current information can the shortest and most efficient voyages be planned. As with all forces of nature, most currents vary considerably with time at a given location. Therefore, it is imperative that DMAHTC receive ocean current reports on a continuous basis.

The general surface currents along the principal trade routes of the world are well known; however, in other less traveled areas the current has not been well defined because of the lack of information. Detailed current reports from those areas are especially valuable.

An urgent need exists for more inshore current reports along all coasts of the world because data in these regions are scarce. Furthermore, information from deep draft ships is needed as this type of vessel is significantly influenced by the deeper layer of surface currents.

The CURRENT REPORT form, NAVOCEANO 3141/6, is designed to facilitate passing information to NAVOCEANO so that all mariners may benefit. The form is self-explanatory and can be used for ocean or coastal current information. Reports by the navigator will contribute significantly to accurate current information for nautical charts, Current Atlases, Pilot Charts, Sailing Directions and other special charts and publications.

3024. Route Reports

Route Reports enable DMAHTC, through its Sailing Directions (Planning Guides), to make recommendations for ocean passages based upon the actual experience of mariners. Of particular importance are reports of routes used by very large ships and from any ship in regions where, from experience and familiarity with local conditions, mariners have devised routes that differ from the “preferred track.” In addition, because of the many and varied local conditions which must be taken into account, coastal route information is urgently needed for updating both Sailing Directions and Coast Pilots.

A Route Report should include a comprehensive summary of the voyage with reference to currents, dangers, weather, and the draft of the vessel. If possible, each report should answer the following questions and should include any other data that may be considered pertinent to the particular route. All information should be given in sufficient detail to assure accurate conclusions and appropriate recommendations. Some questions to be answered are:

1. Why was the route selected?
2. Were anticipated conditions met during the voyage?

CHAPTER 31

THE OCEANS

INTRODUCTION

3100. The Importance Of Oceanography

Oceanography is the application of the sciences to the phenomena of the oceans. It includes a study of their physical, chemical, and geological forms, and biological features. Thus, it embraces the widely separated fields of geography, geology, chemistry, physics, and biology, along with their many subdivisions, such as sedimentation, ecology, bacteriology, biochemistry, hydrodynamics, acoustics, and optics.

The oceans cover 70.8 percent of the surface of the earth. The Atlantic covers 16.2 percent, the Pacific 32.4 percent (3.2 percent more than the land area of the entire earth), the Indian Ocean 14.4 percent, and marginal and adjacent areas (of which the largest is the Arctic Ocean) 7.8 percent. Their extent alone makes them an important subject for study. However, greater incentive lies in their use for transportation, their influence upon weather and climate, and their potential as a source of power, food, fresh water, minerals, and organic substances.

3101. Origin Of The Oceans

The structure of the continents is fundamentally different from that of the oceans. The rocks underlying the ocean floors are more dense than those underlying the continents. According to one theory, all the earth's crust floats on a central liquid core, and the portions that make up the continents, being lighter, float with a higher freeboard. Thus, the thinner areas, composed of heavier rock, form natural basins where water has collected.

The shape of the oceans is constantly changing due to continental drift. The surface of the earth consists of many different "**plates**." These plates are joined along **fracture** or **fault lines**. There is constant and measurable movement of these plates at rates of 0.02 meters per year or more.

The origin of the water in the oceans is unclear. Although some geologists have postulated that all the water existed as vapor in the atmosphere of the primeval earth, and that it fell in great torrents of rain as soon as the earth cooled sufficiently, another school holds that the atmosphere of the original hot earth was lost, and that the water gradually accumulated as it was given off in steam by volcanoes, or worked to the surface in hot springs.

Most of the water on the earth's crust is now in the oceans–about 1,370,000,000 cubic kilometers, or about 85 percent of the total. The mean depth of the ocean is 3,795 meters, and the total area is 360,000,000 square kilometers.

CHEMISTRY OF THE OCEANS

3102. Chemical Description

Oceanographic chemistry may be divided into three main parts: the chemistry of (1) seawater, (2) marine sediments, and (3) organisms living in the sea. The first is of particular interest to the navigator.

Chemical properties of seawater are usually determined by analyzing samples of water obtained at various locations and depths. Samples of water from below the surface are obtained with special bottles designed for this purpose. The open bottles are mounted in a rosette which is attached to the end of a wire cable which contains insulated electrical wires. The rosette is lowered to the depth of the deepest sample, and a bottle is closed electronically. As the rosette is raised to the surface, other bottles are closed at the desired depths. Sensors have also been developed to measure a few chemical properties of sea water continuously.

Physical properties of seawater are dependent primarily upon salinity, temperature, and pressure. However, factors like motion of the water, and the amount of suspended matter, affect such properties as color and transparency, conduction of heat, absorption of radiation, etc.

3103. Salinity

Salinity is a measure of the amount of dissolved solid material in the water. It has been defined as the total amount of solid material in grams contained in one kilogram of seawater when carbonate has been converted to oxide, bromine and iodine replaced by chlorine, and all organic material completely oxidized. It is usually expressed as parts per thousand (by weight), for example the average salinity of sea water is 35 grams per kilogram which would be written "35 ppt" or "35 ‰". Historically the determination of salinity was a slow and difficult process, while the amount of chlorine ions (plus the chlorine equivalent of the bromine

and iodine), called **chlorinity**, could be determined easily and accurately by titration with silver nitrate. From chlorinity, the salinity was determined by a relation based upon the measured ratio of chlorinity to total dissolved substances:

$$\text{Salinity} = 1.80655 \times \text{Chlorinity}$$

This is now called the absolute salinity, (S_A). With titration techniques, salinity could be determined to about 0.02 parts per thousand.

This definition of salinity has now been replaced by the **Practical Salinity Scale**, (S). Using this scale, the salinity of a seawater sample is defined as the ratio between the conducutivity of the sample and the conductivity of a standard potassium chloride (KCl) sample.

As salinity on the practical scale is defined to be conservative with respect to addition and removal of water, the entire salinity range is accessible through precise weight dilution or evaporation without additional definitions. Since practical salinity is a ratio, it has no physical units but is designated **practical salinity units**, or **psu**. The Practical Salinity Scale, combined with modern conductivity cells and bench salinometers, provides salinity measurements which are almost an order of magnitude more accurate and precise, about 0.003 psu, than titration. Numerically, absolute salinity and salinity are nearly equal.

It has also been found that electrical conductivity is better related to density than chlorinity. Since one of the main reasons to measure salinity is to deduce the density, this favors the Practical Salinity Scale as well.

Salinity generally varies between about 33 and 37 psu. However, when the water has been diluted, as near the mouth of a river or after a heavy rainfall, the salinity is somewhat less; and in areas of excessive evaporation, the salinity may be as high as 40 psu. In certain confined bodies of water, notably the Great Salt Lake in Utah, and the Dead Sea in Asia Minor, the salinity is several times this maximum.

3104. Temperature

Temperature in the ocean varies widely, both horizontally and with depth. Maximum values of about 32°C are encountered at the surface in the Persian Gulf in summer, and the lowest possible values of about –2°C; the usual minimum freezing point of seawater) occur in polar regions.

Except in the polar regions, the vertical distribution of temperature in the sea nearly everywhere shows a decrease of temperature with depth. Since colder water is denser (assuming the same salinity), it sinks below warmer water. This results in a temperature distribution just opposite to that of the earth's crust, where temperature increases with depth below the surface of the ground.

In the sea there is usually a mixed layer of isothermal water below the surface, where the temperature is the same as that of the surface. This layer is caused by two physical processes: wind mixing, and convective overturning as surface water cools and becomes more dense. The layer is best developed in the Arctic and Antarctic regions, and in seas like the Baltic and Sea of Japan during the winter, where it may extend to the bottom of the ocean. In the Tropics, the wind-mixed layer may exist to a depth of 125 meters, and may exist throughout the year. Below this layer is a zone of rapid temperature decrease, called the **thermocline**. At a depth greater than 400 m, the temperature everywhere is below 15°C. In the deeper layers, fed by cooled waters that have sunk from the surface in the Arctic and Antarctic, temperatures as low as –2°C exist.

In the colder regions the cooling creates the convective overturning and isothermal water in the winter; but in the summer a seasonal thermocline is created as the upper water becomes warmer. A typical curve of temperature at various depths is shown in Figure 3110a. Temperature is commonly measured with either a platinum or copper resistance thermometer or a thermistor (devices that measure the change in conductivity of a semiconductor with change in temperature). The **CTD (conductivity-temperature-depth)** is an instrument that generates continuous signals as it is lowered into the ocean; temperature is determined by means of a platinum resistance thermometer, salinity by conductivity, and depth by pressure. These signals are transmitted to the surface through a cable and recorded. Accuracy of temperature measurement is 0.005°C and resolution an order of magnitude better.

A method commonly used to measure upper ocean temperature profiles from a vessel which is underway is the **expendable bathythermograph (XBT)**. The XBT uses a thermistor and is connected to the vessel by a fine wire. The wire is coiled inside the probe, and as the probe freefalls in the ocean, the wire pays out. Depth is determined by elapsed time and a known sink rate. Depth range is determined by the amount of wire stored in the probe; the most common model has a depth range of 450 meters. At the end of the drop, the wire breaks and the probe falls to the ocean bottom. One instrument of this type is dropped from an aircraft; the data is relayed to the aircraft from a buoy to which the wire of the XBT is attached. The accuracy and precision of an XBT is about 0.1°C.

3105. Pressure

The appropriate international standard (SI) unit for pressure in oceanography is 1 $kPa = 10^3\ Pa$ where Pa is a Pascal and is equal to one Newton per square meter. A more commonly used unit is a bar, which is nearly equal to 1 atmosphere (atmospheric pressure is measured with a barometer and may be read as millibars). Water pressure is expressed in terms of decibars, 10 of these being equal to 1 bar. One decibar is equal to nearly $1\ ^1/_2$ pounds per square inch. This unit is convenient because it is very nearly the pressure exerted by 1 meter of water. Thus, the pressure in

decibars is approximately the same as the depth in meters, the unit of depth.

Although virtually all of the physical properties of seawater are affected to a measurable extent by pressure, the effect is not as great as those of salinity and temperature. Pressure is of particular importance to submarines, directly because of the stress it induces on the hull and structures, and indirectly because of its effect upon buoyancy.

3106. Density

Density is mass per unit of volume. The appropriate SI unit is kilograms per cubic meter. The density of seawater depends upon salinity, temperature, and pressure. At constant temperature and pressure, density varies with salinity. A temperature of 0°C and atmospheric pressure are considered standard for density determination. The effects of thermal expansion and compressibility are used to determine the density at other temperatures and pressures. Density changes at the surface generally do not affect the draft or trim of a ship. But density changes at a particular subsurface pressure affect the buoyancy of submarines because they are ballasted to be neutrally buoyant. For oceanographers, density is important because of its relationship to ocean currents.

Open ocean values of density range from about 1,021 kilograms per cubic meter at the surface to about 1,070 kilograms per cubic meter at 10,000 meters depth. As a matter of convenience, it is usual in oceanography to define a density anomaly which is equal to the density minus 1,000 kilograms per cubic meter. Thus, when an oceanographer speaks of seawater with a density of 25 kilograms per cubic meter, the actual density is 1,025 kilograms per cubic meter.

The greatest changes in density of seawater occur at the surface, where the water is subject to influences not present at depths. At the surface, density is decreased by precipitation, run-off from land, melting ice, or heating. When the surface water becomes less dense, it tends to float on top of the more dense water below. There is little tendency for the water to mix, and so the condition is one of stability. The density of surface water is increased by evaporation, formation of sea ice, and by cooling. If the surface water becomes more dense than that below, convection currents cause vertical mixing. The more dense surface water sinks and mixes with less dense water below. The resultant layer of water is of intermediate density. This process continues until the density of the mixed layer becomes less than that of the water below. The convective circulation established as part of this process can create very deep uniform mixed layers.

If the surface water becomes sufficiently dense, it sinks all the way to the bottom. If this occurs in an area where horizontal flow is unobstructed, the water which has descended spreads to other regions, creating a dense bottom layer. Since the greatest increase in density occurs in polar regions, where the air is cold and great quantities of ice form, the cold, dense polar water sinks to the bottom and then spreads to lower latitudes. In the Arctic Ocean region, the cold, dense water is confined by the Bering Strait and the underwater ridge from Greenland to Iceland to Europe. In the Antarctic, however, there are no similar geographic restrictions and large quantities of very cold, dense water formed there flow to the north along the ocean bottom. This process has continued for a sufficiently long period of time that the entire ocean floor is covered with this dense water, thus explaining the layer of cold water at great depths in all the oceans.

In some respects, oceanographic processes are similar to those occurring in the atmosphere. The convective circulation in the ocean is similar to that in the atmosphere. Masses of water of uniform characteristics are analogous to air masses.

3107. Compressibility

Seawater is nearly incompressible, its coefficient of compressibility being only 0.000046 per bar under standard conditions. This value changes slightly with changes in temperature or salinity. The effect of compression is to force the molecules of the substance closer together, causing it to become more dense. Even though the compressibility is low, its total effect is considerable because of the amount of water involved. If the compressibility of seawater were zero, sea level would be about 90 feet higher than it is now.

Compressibility is inversely proportional to temperature, i.e., cold water is more compressible than warm water. Waters which flow into the North Atlantic from the Mediterranean and Greenland Seas are equal in density, but because the water from the Greenland Sea is colder, it is more compressible and therefore becomes denser at depth. These waters from the Greenland Sea are therefore found beneath those waters which derive their properties from the Mediterranean.

3108. Viscosity

Viscosity is resistance to flow. Seawater is slightly more viscous than freshwater. Its viscosity increases with greater salinity, but the effect is not nearly as marked as that occurring with decreasing temperature. The rate is not uniform, becoming greater as the temperature decreases. Because of the effect of temperature upon viscosity, an incompressible object might sink at a faster rate in warm surface water than in colder water below. However, for most objects, this effect may be more than offset by the compressibility of the object.

The actual relationships existing in the ocean are considerably more complex than indicated by the simple explanation here, because of turbulent motion within the sea. The disturbing effect is called **eddy viscosity**.

3109. Specific Heat

Specific Heat is the amount of heat required to raise the temperature of a unit mass of a substance a stated amount. In oceanography, specific heat is stated, in SI units,

as the number of Joules needed to raise 1 kilogram of a given substance 1°C. Specific heat at constant pressure is usually the quantity desired when liquids are involved, but occasionally the specific heat at constant volume is required. The ratio of these two quantities is directly related to the speed of sound in seawater.

The specific heat of seawater decreases slightly as salinity increases. However, it is much greater than that of land. The ocean is a giant storage area for heat. It can absorb large quantities of heat with very little change in temperature. This is partly due to the high specific heat of water and partly due to mixing in the ocean that distributes the heat throughout a layer. Land has a lower specific heat and, in addition, all heat is lost or gained from a thin layer at the surface; there is no mixing. This accounts for the greater temperature range of land and the atmosphere above it, resulting in monsoons, and the familiar land and sea breezes of tropical and temperate regions.

3110. Sound Speed

The speed of sound in sea water is a function of its density, compressibility and, to a minor extent, the ratio of specific heat at constant pressure to that at constant volume. As these properties depend on the temperature, salinity and pressure (depth) of sea water, it is customary to relate the speed of sound directly to the water temperature, salinity and pressure. An increase in any of these three properties causes an increase in the sound speed; the converse is true also. Figure 3110a portrays typical mid-ocean profiles of temperature and salinity; the resultant sound speed profile is shown in Figure 3110b.

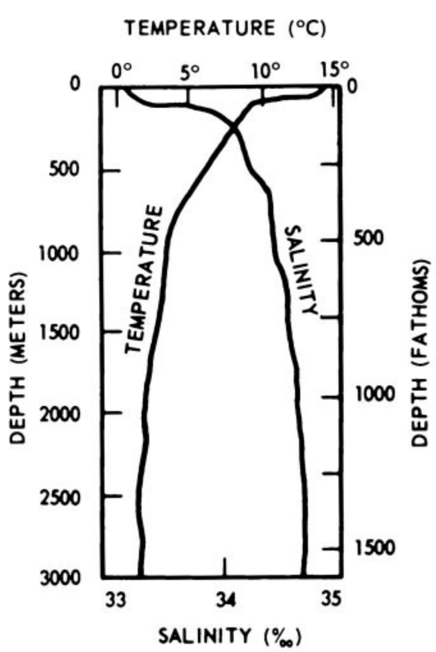


Figure 3110a. Typical variation of temperature and salinity with depth for a mid-latitude location.

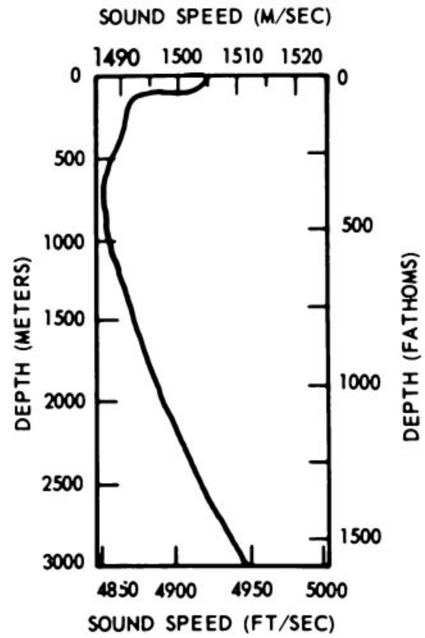


Figure 3110b. Resultant sound speed profile based on the temperature and salinity profile in Figure 3110a.

The speed of sound changes by 3 to 5 meters per second per °C temperature change, by about 1.3 meters per second per psu salinity change and by about 1.7 meters per second per 100 m depth change. A simplified formula adapted from Wilson's (1960) equation for the computation of the sound speed in sea water is:

$$U = 1449 + 4.6T - 0.055T^2 + 0.0003T^3 + 1.39(S - 35) + 0.017D$$

where U is the speed (m/s), T is the temperature (°C), S is the salinity (psu), and D is depth (m).

3111. Thermal Expansion

One of the more interesting differences between salt and fresh water relates to thermal expansion. Saltwater continues to become more dense as it cools to the freezing point; freshwater reaches maximum density at 4°C and then expands (becomes less dense) as the water cools

to 0°C and freezes. This means that the convective mixing of freshwater stops at 4°C; freezing proceeds very rapidly beyond that point. The rate of expansion with increased temperature is greater in seawater than in fresh water. Thus, at temperature 15°C, and atmospheric pressure, the coefficient of thermal expansion is 0.000151 per degree Celsius for freshwater, and 0.000214 per degree Celsius for average seawater. The coefficient of thermal expansion increases not only with greater salinity, but also with increased temperature and pressure. At a salinity of 35 psu, the coefficient of surface water increases from 0.000051 per degree Celsius at 0°C to 0.000334 per degree Celsius at 31°C. At a constant temperature of 0°C and a salinity of 34.85 psu, the coefficient increases to 0.000276 per degree Celsius at a pressure of 10,000 decibars (a depth of approximately 10,000 meters).

3112. Thermal Conductivity

In water, as in other substances, one method of heat transfer is by conduction. Freshwater is a poor conductor of heat, having a coefficient of thermal conductivity of 582 Joules per second per meter per degree Celsius. For seawater it is slightly less, but increases with greater temperature or pressure.

However, if turbulence is present, which it nearly always is to some extent, the processes of heat transfer are altered. The effect of turbulence is to increase greatly the rate of heat transfer. The "eddy" coefficient used in place of the still-water coefficient is so many times larger, and so dependent upon the degree of turbulence, that the effects of temperature and pressure are not important.

3113. Electrical Conductivity

Water without impurities is a very poor conductor of electricity. However, when salt is in solution in water, the salt molecules are ionized and become carriers of electricity. (What is commonly called freshwater has many impurities and is a good conductor of electricity; only pure distilled water is a poor conductor.) Hence, the electrical conductivity of seawater is directly proportional to the number of salt molecules in the water. For any given salinity, the conductivity increases with an increase in temperature.

3114. Radioactivity

Although the amount of radioactive material in seawater is very small, this material is present in marine sediments to a greater extent than in the rocks of the earth's crust. This is probably due to precipitation of radium or other radioactive material from the water. The radioactivity of the top layers of sediment is less than that of deeper layers. This may be due to absorption of radioactive material in the soft tissues of marine organisms.

3115. Transparency

The two basic processes that alter the underwater distribution of light are absorption and scattering. Absorption is a change of light energy into other forms of energy; scattering entails a change in direction of the light, but without loss of energy. If seawater were purely absorbing, the loss of light with distance would be given by $I_x = I_0 e^{-ax}$ where I_x is the intensity of light at distance x, I_0 is the intensity of light at the source, and "a" is the absorption coefficient in the same units with which distance is measured. In a pure scattering medium, the transmission of light is governed by the same power law only in this case the exponential term is $I_0 e^{-bx}$, where "b" is the volume scattering coefficient. The attenuation of light in the ocean is defined as the sum of absorption and scattering so that the attenuation coefficient, c, is given by c = a + b. In the ocean, the attenuation of light with depth depends not only on the wavelength of the light but also the clarity of the water. The clarity is mostly controlled by biological activity although at the coast, sediments transported by rivers or resuspended by wave action can strongly attenuate light.

Attenuation in the sea is measured with a **transmissometer**. Transmissometers measure the attenuation of light over a fixed distance using a monochromatic light source which is close to red in color. Transmissometers are designed for in situ use and are usually attached to a CTD.

Since sunlight is critical for almost all forms of plant life in the ocean, oceanographers developed a simple method to measure the penetration of sunlight in the sea using a white disk 31 centimeters (a little less than 1 foot) in diameter which is called a **Secchi disk**. This is lowered into the sea, and the depth at which it disappears is recorded. In coastal waters the depth varies from about 5 to 25 meters. Offshore, the depth is usually about 45 to 60 meters. The greatest recorded depth at which the disk has disappeared is 79 meters in the eastern Weddell Sea. These depths, D, are sometimes reported as a diffuse attenuation (or "extinction") coefficient, k, where k = 1.7/D and the penetration of sunlight is given by $I_z = I_0 e^{-kz}$ where z is depth and I_0 is the energy of the sunlight at the ocean's surface.

3116. Color

The color of seawater varies considerably. Water of the Gulf Stream is a deep indigo blue, while a similar current off Japan was named Kuroshio (Black Stream) because of the dark color of its water. Along many coasts the water is green. In certain localities a brown or brownish-red water has been observed. Colors other than blue are caused by biological sources, such as plankton, or by suspended sediments from river runoff.

Offshore, some shade of blue is common, particularly in tropical or subtropical regions. It is due to scattering of sunlight by minute particles suspended in the water, or by molecules of the water itself. Because of its short wavelength, blue light is more effectively scattered than light of

longer waves. Thus, the ocean appears blue for the same reason that the sky does. The green color often seen near the coast is a mixture of the blue due to scattering of light and a stable soluble yellow pigment associated with phytoplankton. Brown or brownish-red water receives its color from large quantities of certain types of **algae**, microscopic plants in the sea, or from river runoff.

3117. Bottom Relief

Compared to land, relatively little is known of relief below the surface of the sea. The development of an effective echo sounder in 1922 greatly simplified the determination of bottom depth. Later, a recording echo sounder was developed to permit the continuous tracing of a bottom profile. The latest sounding systems employ an array of echosounders aboard a single vessel, which continuously sound a wide swath of ocean floor. This has contributed immensely to our knowledge of bottom relief. By this means, many undersea mountain ranges, volcanoes, rift valleys, and other features have been discovered.

Along most of the coasts of the continents, the bottom slopes gradually downward to a depth of about 130 meters or somewhat less, where it falls away more rapidly to greater depths. This **continental shelf** averages about 65 kilometers in width, but varies from nothing to about 1400 kilometers, the widest part being off the Siberian Arctic coast. A similar shelf extending outward from an island or group of islands is called an **island shelf**. At the outer edge of the shelf, the steeper slope of 2° to 4° is called the **continental slope**, or the **island slope**, according to whether it surrounds a continent or a group of islands. The shelf itself is not uniform, but has numerous hills, ridges, terraces, and canyons, the largest being comparable in size to the Grand Canyon.

The relief of the ocean floor is comparable to that of land. Both have steep, rugged mountains, deep canyons, rolling hills, plains, etc. Most of the ocean floor is considered to be made up of a number of more-or-less circular or oval depressions called **basins**, surrounded by walls (**sills**) of lesser depth.

A wide variety of submarine features has been identified and defined. Some of these are shown in Figure 3117. Detailed definitions and descriptions of such features can be found in Kennett (1982) or Fairbridge (1966). The term **deep** may be used for a very deep part of the ocean, generally that part deeper than 6,000 meters.

The average depth of water in the oceans is 3795 meters (2,075 fathoms), as compared to an average height of land above the sea of about 840 meters. The greatest known depth is 11,524 meters, in the Marianas Trench in the Pacific. The highest known land is Mount Everest, 8,840 meters. About 23 percent of the ocean is shallower than 3,000 meters, about 76 percent is between 3,000 and 6,000 meters, and a little more than 1 percent is deeper than 6,000 meters.

3118. Marine Sediments

The ocean floor is composed of material deposited through the ages. This material consists principally of (1) earth and rocks washed into the sea by streams and waves, (2) volcanic ashes and lava, and (3) the remains of marine organisms. Lesser amounts of land material are carried into the sea by glaciers, blown out to sea by wind, or deposited by chemical means. This latter process is responsible for the **manganese nodules** that cover some parts of the ocean floor. In the ocean, the material is transported by ocean currents, waves, and ice. Near shore the material is deposited at the rate of about 8 centimeters in 1,000 years, while in the deep water offshore the rate is only about 1 centimeter in 1,000 years. Marine deposits in water deep enough to be relatively free from wave action are subject to little erosion. Recent studies have shown that some bottom currents are strong enough to move sediments. There are turbidity currents, similar to land slides, that move large masses of sediments. **Turbidity currents** have been known to rip apart large transoceanic cables on the ocean bottom. Because of this and the slow rate of deposit, marine sediments provide a better geological record than does the land.

Marine sediments are composed of individual particles of all sizes from the finest clay to large boulders. In general, the inorganic deposits near shore are relatively coarse (sand, gravel, shingle, etc.), while those in deep water are much finer (clay). In some areas the siliceous remains of marine organisms or calcareous deposits of either organic or inorganic origin predominate on the ocean floor.

A wide range of colors is found in marine sediments. The lighter colors (white or a pale tint) are usually associated with coarse-grained quartz or limestone deposits. Darker colors (red, blue, green, etc.) are usually found in mud having a predominance of some mineral substance, such as an oxide of iron or manganese. Black mud is often found in an area that is little disturbed, such as at the bottom of an inlet or in a depression without free access to other areas.

Marine sediments are studied primarily through bottom samples. Samples of surface deposits are obtained by means of a “snapper” (for mud, sand, etc.) or “dredge” (usually for rocky material). If a sample of material below the bottom surface is desired, a “coring” device is used. This device consists essentially of a tube driven into the bottom by weights or explosives. A sample obtained in this way preserves the natural order of the various layers. Samples of more than 100 feet in depth have been obtained using coring devices.

3119. Satellite Oceanography

Weather satellites are able to observe ocean surface temperatures in cloud free regions by using infrared sensors. Although these sensors are only able to penetrate a few millimeters into the ocean, the temperatures that they yield are

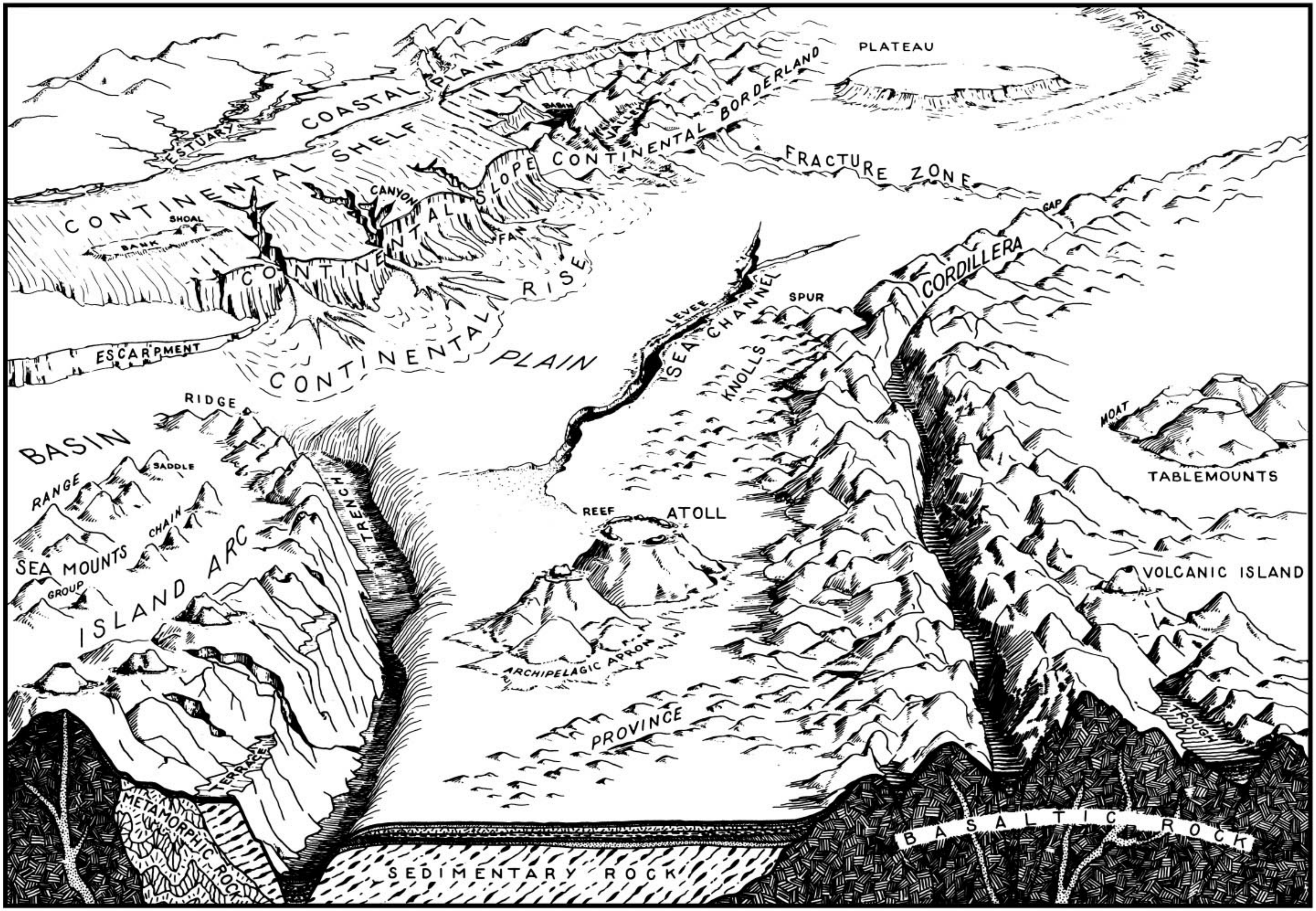


Figure 3117. Ocean basin features.

representative of upper ocean conditions except when the air is absolutely calm during daylight hours. For cloud covered regions, it is usually possible to wait a few days for the passage of a cold front and then use a sequence of infrared images to map the ocean temperature over a region. The patterns of warm and cold water yield information on ocean currents, the existence of fronts and eddies, and the temporal and spatial scales of ocean processes.

Other satellite sensors are capable of measuring ocean color, ice coverage, ice age, ice edge, surface winds and seas, ocean currents, and the shape of the surface of the ocean. (The latter is controlled by gravity and ocean circulation patterns. See Chapter 2.) The perspective provided by these satellites is a global one and in some cases they yield sufficient quantities of data that synoptic charts of the ocean surface, similar to weather maps and pilot charts, can be provided to the mariner for use in navigation.

The accuracy of satellite observations of the ocean surface depends, in many cases, on calibration procedures which use observations of sea surface conditions provided by mariners. These observations include marine weather observations, expendable bathythermograph soundings, and currents measured by electromagnetic logs or acoustic Doppler current profilers. Care and diligence in these observations will improve the accuracy and the quality of satellite data.

3120. Synoptic Oceanography

Oceanographic data provided by ships, buoys, and satellites are analyzed by the Naval Oceanographic Office and the National Meteorological Center. These data are utilized in computer models both to provide a synoptic view of ocean conditions and to predict how these conditions will change in the future. These products are available to the mariner via radio or satellite.

CHAPTER 32

OCEAN CURRENTS

TYPES AND CAUSES OF CURRENTS

3200. Definitions

The movement of ocean water is one of the two principal sources of discrepancy between dead reckoned and actual positions of vessels. Water in motion is called a current; the direction toward which it moves is called set, and its speed is called drift. Modern shipping speeds have lessened the impact of currents on a typical voyage, and since electronic navigation allows continuous adjustment of course, there is less need to estimate current set and drift before setting the course to be steered. Nevertheless, a knowledge of ocean currents can be used in cruise planning to reduce transit times. Ocean current models are an integral part of ship routing systems.

Oceanographers have developed a number of methods of classifying currents in order to facilitate descriptions of their physics and geography. Currents may be referred to according to their forcing mechanism as either **wind driven** or **thermohaline**. Alternatively, they may be classified according to their depth (surface, intermediate, deep or bottom). The surface circulation of the world ocean is mostly wind driven. Thermohaline currents are driven by differences in heat and salt and are associated with the sinking of dense water at high latitudes; the currents driven by thermohaline forcing are typically subsurface. Note that this classification scheme is not unambiguous; the circumpolar current, which is wind driven, extends from the surface to the bottom.

A **periodic current** is one for which the speed or direction changes cyclically at somewhat regular intervals, such as a tidal current. A **seasonal current** is one which changes in speed or direction due to seasonal winds. The mean circulation of the ocean consists of semi-permanent currents which experience relatively little periodic or seasonal change.

A **coastal current** flows roughly parallel to a coast, outside the surf zone, while a **longshore current** is one parallel to a shore, inside the surf zone, generated by waves striking the beach at an angle. Any current some distance from the shore may be called an **offshore current**, and one close to the shore an **inshore current**.

3201. Causes Of Ocean Currents

The primary generating forces are wind and differences in density of the water caused by variations in heat and salt. Currents generated by these forces are modified by such factors as depth of water, underwater topography including shape of the basin in which the current is running, extent and location of land, and deflection by the rotation of the earth.

3202. Wind Driven Currents

The stress of wind blowing across the sea causes a surface layer of water to move. Due to the low viscosity of water, this stress is not directly communicated to the ocean interior, but is balanced by the Coriolis force within a relatively thin surface layer, 10-200m thick. This layer is called the **Ekman layer** and the motion of this layer is called the **Ekman transport**. Because of the deflection by the Coriolis force, the Ekman transport is not in the direction of the wind, but is 90° to the right in the Northern Hemisphere and 90° toward the left in the Southern Hemisphere. The amount of water flowing in this layer depends only upon the wind and the Coriolis force and is independent of the depth of the Ekman layer and the viscosity of the water.

The large scale convergence or divergence of Ekman transport serves to drive the general ocean circulation. Consider the case of the Northern Hemisphere subtropics. To the south lie easterly winds with associated northward Ekman transport. To the north lie westerly winds with southward Ekman transport. The convergence of these Ekman transports is called **Ekman pumping** and results in a thickening of the upper ocean and a increase in the depth of the thermocline. The resulting subsurface pressure gradients, balanced by the Coriolis force, give rise to the anticyclonic subtropical gyres found at mid latitudes in each ocean basin. In subpolar regions, Ekman suction produces cyclonic gyres.

These wind driven gyres are not symmetrical. Along the western boundary of the oceans, currents are narrower, stronger, and deeper, often following a meandering course. These currents are sometimes called a **stream**. In contrast, currents in mid-ocean and at the eastern boundary, are often broad, shallow and slow-moving. Sometimes these are called **drift currents**.

Within the Ekman layer, the currents actually form a spiral. At the surface, the difference between wind direction and surface wind-current direction varies from about 15° along shallow coastal areas to a maximum of 45° in the deep oceans. As the motion is transmitted to successively deep layers, the Coriolis force continues to deflect the current. At

the bottom of the Ekman layer, the current flows in the opposite direction to the surface current. This shift of current directions with depth, combined with the decrease in velocity with depth, is called the **Ekman spiral**.

The velocity of the surface current is the sum of the velocities of the Ekman, geostrophic, tidal, and other currents. The Ekman surface current or wind drift current depends upon the speed of the wind, its constancy, the length of time it has blown, and other factors. In general, however, wind drift current is about 2 percent of the wind speed, or a little less, in deep water where the wind has been blowing steadily for at least 12 hours.

3203. Currents Related To Density Differences

The density of water varies with salinity, temperature, and pressure. At any given depth, the differences in density are due only to differences in temperature and salinity. With sufficient data, maps showing geographical density distribution at a certain depth can be drawn, with lines connecting points of equal density. These lines would be similar to isobars on a weather map and serve an analogous purpose, showing areas of high density and those of low density. In an area of high density, the water surface is lower than in an area of low density, the maximum difference in height being about 1 meter in 100 km. Because of this difference, water tends to flow from an area of higher water (low density) to one of lower water (high density). But due to rotation of the earth, it is deflected by the Coriolis force or toward the right in the Northern Hemisphere, and toward the left in the Southern Hemisphere. This balance, between subsurface pressure fields and the Coriolis force, is called **geostrophic equilibrium**. At a given latitude, the greater the density gradient (rate of change with distance), the faster the geostrophic current.

OCEANIC CIRCULATION

3204. Introduction

A number of ocean currents flow with great persistence, setting up a circulation that continues with relatively little change throughout the year. Because of the influence of wind in creating current, there is a relationship between this oceanic circulation and the general circulation of the atmosphere. The oceanic circulation is shown on the chart following this page (winter N. hemisphere), with the names of the major ocean currents. Some differences in opinion exist regarding the names and limits of some of the currents, but those shown are representative. Speed may vary somewhat with the season. This is particularly noticeable in the Indian Ocean and along the South China coast, where currents are influenced to a marked degree by the monsoons.

3205. Southern Ocean Currents

The Southern Ocean has no meridional boundaries and its waters are free to circulate around the world. It serves as a conveyor belt for the other oceans, exchanging waters between them. The northern boundary of the Southern Ocean is marked by the Subtropical Convergence zone. This zone marks the transition from the temperate region of the ocean to the polar region and is associated with the surfacing of the main thermocline. This zone is typically found at 40°S but varies with longitude and season.

In the Antarctic, the circulation is generally from west to east in a broad, slow-moving current extending completely around Antarctica. This is called the **Antarctic Circumpolar Current** or the **West Wind Drift**, and it is formed partly by the strong westerly wind in this area, and partly by density differences. This current is augmented by the Brazil and Falkland Currents in the Atlantic, the East Australia Current in the Pacific, and the Agulhas Current in the Indian Ocean. In return, part of it curves northward to form the Cape Horn, Falkland, and most of the Benguela Currents in the Atlantic, and the Peru Current in the Pacific.

In a narrow zone next to the Antarctic continent, a westward flowing coastal current is usually found. This current is called the **East Wind Drift** because it is attributed to the prevailing easterly winds which occur there.

3206. Atlantic Ocean Currents

The trade winds set up a system of equatorial currents which at times extends over as much as 50° of latitude or more. There are two westerly flowing currents conforming generally with the areas of trade winds, separated by a weaker, easterly flowing countercurrent.

The **North Equatorial Current** originates to the northward of the Cape Verde Islands and flows almost due west at an average speed of about 0.7 knot.

The **South Equatorial Current** is more extensive. It starts off the west coast of Africa, south of the Gulf of Guinea, and flows in a generally westerly direction at an average speed of about 0.6 knot. However, the speed gradually increases until it may reach a value of 2.5 knots, or more, off the east coast of South America. As the current approaches Cabo de Sao Roque, the eastern extremity of South America, it divides, the southern part curving toward the south along the coast of Brazil, and the northern part being deflected northward by the continent of South America.

Between the North and South Equatorial Currents, the weaker **North Equatorial Countercurrent** sets toward the east in the general vicinity of the doldrums. This is fed by

water from the two westerly flowing equatorial currents, particularly the South Equatorial Current. The extent and strength of the Equatorial Countercurrent changes with the seasonal variations of the wind. It reaches a maximum during July and August, when it extends from about 50° west longitude to the Gulf of Guinea. During its minimum, in December and January, it is of very limited extent, the western portion disappearing altogether.

That part of the South Equatorial Current flowing along the northern coast of South America which does not feed the Equatorial Countercurrent unites with the North Equatorial Current at a point west of the Equatorial Countercurrent. A large part of the combined current flows through various passages between the Windward Islands and into the Caribbean Sea. It sets toward the west, and then somewhat north of west, finally arriving off the Yucatan peninsula. From there, the water enters the Gulf of Mexico and forms the **Loop Current**; the path of the Loop Current is variable with a 13-month period. It begins by flowing directly from Yucatan to the Florida Straits, but gradually grows to flow anticyclonically around the entire Eastern Gulf; it then collapses, again following the direct path from Yucatan to the Florida Straits, with the loop in the Eastern Gulf becoming a separate eddy which slowly flows into the Western Gulf.

Within the Straits of Florida, the Loop Current feeds the beginnings of the most remarkable of American ocean currents, the **Gulf Stream**. Off the southeast coast of Florida this current is augmented by the **Antilles Current** which flows along the northern coasts of Puerto Rico, Hispaniola, and Cuba. Another current flowing eastward of the Bahamas joins the stream north of these islands.

The Gulf Stream follows generally along the east coast of North America, flowing around Florida, northward and then northeastward toward Cape Hatteras, and then curving toward the east and becoming broader and slower. After passing the Grand Banks, it turns more toward the north and becomes a broad drift current flowing across the North Atlantic. The part in the Straits of Florida is sometimes called the **Florida Current**.

A tremendous volume of water flows northward in the Gulf Stream. It can be distinguished by its deep indigo-blue color, which contrasts sharply with the dull green of the surrounding water. It is accompanied by frequent squalls. When the Gulf Stream encounters the cold water of the Labrador Current, principally in the vicinity of the Grand Banks, there is little mixing of the waters. Instead, the junction is marked by a sharp change in temperature. The line or surface along which this occurs is called the **cold wall**. When the warm Gulf Stream water encounters cold air, evaporation is so rapid that the rising vapor may be visible as frost smoke.

Investigations have shown that the current itself is much narrower and faster than previously supposed, and considerably more variable in its position and speed. The maximum current off Florida ranges from about 2 to 4 knots. Northward, the speed is generally less, and it decreases further after the current passes Cape Hatteras. As the stream meanders and shifts position, eddies sometimes break off and continue as separate, circular flows until they dissipate. Boats in the Newport-Bermuda sailing yacht race have been known to be within sight of each other and be carried in opposite directions by different parts of the same current. This race is generally won by the boat which catches an eddy just right. As the current shifts position, its extent does not always coincide with the area of warm, blue water. When the sea is relatively smooth, the edges of the current are marked by ripples.

A recirculation region exists adjacent to and southwest of the Gulf Stream. The flow of water in the recirculation region is opposite to that in the Gulf Stream and surface currents are much weaker, generally less than half a knot.

As the Gulf Stream continues eastward and northeastward beyond the Grand Banks, it gradually widens and decreases speed until it becomes a vast, slow-moving current known as the **North Atlantic Current**, in the general vicinity of the prevailing westerlies. In the eastern part of the Atlantic it divides into the **Northeast Drift Current** and the **Southeast Drift Current**.

The Northeast Drift Current continues in a generally northeasterly direction toward the Norwegian Sea. As it does so, it continues to widen and decrease speed. South of Iceland it branches to form the **Irminger Current** and the **Norway Current**. The Irminger Current curves toward the north and northwest to join the East Greenland Current southwest of Iceland. The Norway Current continues in a northeasterly direction along the coast of Norway. Part of it, the **North Cape Current**, rounds North Cape into the Barents Sea. The other part curves toward the north and becomes known as the **Spitsbergen Current**. Before reaching Svalbard (Spitsbergen), it curves toward the west and joins the cold **East Greenland Current** flowing southward in the Greenland Sea. As this current flows past Iceland, it is further augmented by the Irminger Current.

Off Kap Farvel, at the southern tip of Greenland, the East Greenland Current curves sharply to the northwest following the coastline. As it does so, it becomes known as the **West Greenland Current**, and its character changes from that of an intense western boundary current to a weaker eastern boundary current. This current continues along the west coast of Greenland, through Davis Strait, and into Baffin Bay.

In Baffin Bay the West Greenland Current generally follows the coast, curving westward off Kap York to form the southerly flowing **Labrador Current**. This cold current flows southward off the coast of Baffin Island, through Davis Strait, along the coast of Labrador and Newfoundland, to the Grand Banks, carrying with it large quantities of ice. Here it encounters the warm water of the Gulf Stream, creating the cold wall. Some of the cold water flows southward along the east coast of North America, inshore of the Gulf Stream, as far as Cape Hatteras. The remainder curves toward the east and flows along the northern edge of the North Atlantic and Northeast Drift Currents,

gradually merging with them.

The **Southeast Drift Current** curves toward the east, southeast, and then south as it is deflected by the coast of Europe. It flows past the Bay of Biscay, toward southeastern Europe and the Canary Islands, where it continues as the **Canary Current**. In the vicinity of the Cape Verde Islands, this current divides, part of it curving toward the west to help form the **North Equatorial Current**, and part of it curving toward the east to follow the coast of Africa into the Gulf of Guinea, where it is known as the **Guinea Current**. This current is augmented by the **North Equatorial Countercurrent** and, in summer, it is strengthened by monsoon winds. It flows in close proximity to the South Equatorial Current, but in the opposite direction. As it curves toward the south, still following the African coast, it merges with the South Equatorial Current.

The clockwise circulation of the North Atlantic leaves a large central area between the recirculation region and the Canary Current which has no well-defined currents. This area is known as the **Sargasso Sea**, from the large quantities of sargasso or gulfweed encountered there.

That branch of the South Equatorial Current which curves toward the south off the east coast of South America, follows the coast as the warm, highly-saline **Brazil Current**, which in some respects resembles a weak Gulf Stream. Off Uruguay it encounters the colder, less-salty **Falkland** or **Malvinas Current** forming a sharp meandering front in which eddies may form. The two currents curve toward the east to form the broad, slow-moving, **South Atlantic Current** in the general vicinity of the prevailing westerlies and the front dissipates somewhat. This current flows eastward to a point west of the Cape of Good Hope, where it curves northward to follow the west coast of Africa as the strong **Benguela Current**, augmented somewhat by part of the **Agulhas Current** flowing around the southern part of Africa from the Indian Ocean. As it continues northward, the current gradually widens and slows. At a point east of St. Helena Island it curves westward to continue as part of the South Equatorial Current, thus completing the counterclockwise circulation of the South Atlantic. The Benguela Current is also augmented somewhat by the West Wind Drift, a current which flows easterly around Antarctica. As the West Wind Drift flows past Cape Horn, that part in the immediate vicinity of the cape is called the **Cape Horn Current**. This current rounds the cape and flows in a northerly and northeasterly direction along the coast of South America as the Falkland or Malvinas Current.

3207. Pacific Ocean Currents

Pacific Ocean currents follow the general pattern of those in the Atlantic. The **North Equatorial Current** flows westward in the general area of the northeast trades, and the **South Equatorial Current** follows a similar path in the region of the southeast trades. Between these two, the weaker **North Equatorial Countercurrent** sets toward the east, just north of the equator.

After passing the Mariana Islands, the major part of the North Equatorial Current curves somewhat toward the northwest, past the Philippines and Taiwan. Here it is deflected further toward the north, where it becomes known as the **Kuroshio**, and then toward the northeast past the Nansei Shoto and Japan, and on in a more easterly direction. Part of the Kuroshio, called the **Tsushima Current**, flows through Tsushima Strait, between Japan and Korea, and the Sea of Japan, following generally the northwest coast of Japan. North of Japan it curves eastward and then southeastward to rejoin the main part of the Kuroshio. The limits and volume of the Kuroshio are influenced by the monsoons, being augmented during the season of southwesterly winds, and diminished when the northeasterly winds are prevalent.

The Kuroshio (Japanese for “Black Stream”) is so named because of the dark color of its water. It is sometimes called the **Japan Current**. In many respects it is similar to the Gulf Stream of the Atlantic. Like that current, it carries large quantities of warm tropical water to higher latitudes, and then curves toward the east as a major part of the general clockwise circulation in the Northern Hemisphere. As it does so, it widens and slows, continuing on between the Aleutians and the Hawaiian Islands, where it becomes known as the **North Pacific Current**.

As this current approaches the North American continent, most of it is deflected toward the right to form a clockwise circulation between the west coast of North America and the Hawaiian Islands called the **California Current**. This part of the current has become so broad that the circulation is generally weak. Near the coast, the southeastward flow intensifies and average speeds are about 0.8 knot. But the flow pattern is complex, with offshore directed jets often found near more prominent capes, and poleward flow often found over the upper slope and outer continental shelf. It is strongest near land. Near the southern end of Baja California, this current curves sharply to the west and broadens to form the major portion of the North Equatorial Current.

During the winter, a weak countercurrent flows northwestward, inshore of the southeastward flowing California Current, along the west coast of North America from Baja California to Vancouver Island. This is called the **Davidson Current**.

Off the west coast of Mexico, south of Baja California the current flows southeastward during the winter as a continuation of part of the California Current. During the summer, the current in this area is northwestward as a continuation of the North Equatorial Countercurrent.

As in the Atlantic, there is in the Pacific a counterclockwise circulation to the north of the clockwise circulation. Cold water flowing southward through the western part of Bering Strait between Alaska and Siberia, is joined by water circulating counterclockwise in the Bering Sea to form the **Oyashio**. As the current leaves the strait, it curves toward the right and flows southwesterly along the coast of Siberia and the Kuril Islands. This current brings quantities of sea ice, but no icebergs. When it encounters the Kuroshio, the

Oyashio curves southward and then eastward, the greater portion joining the Kuroshio and North Pacific Current.

The northern branch of the North Pacific Current curves in a counterclockwise direction to form the **Alaska Current**, which generally follows the coast of Canada and Alaska. When the Alaska Current turns to the southwest and flows along the Kodiak Island and the Alaska Peninsula, its character changes to that of a western boundary current and it is called the Alaska Stream. When this westward flow arrives off the Aleutian Islands, it is less intense and becomes known as the **Aleutian Current**. Part of it flows along the southern side of these islands to about the 180th meridian, where it curves in a counterclockwise direction and becomes an easterly flowing current, being augmented by the northern part of the Oyashio. The other part of the Aleutian Current flows through various openings between the Aleutian Islands, into the Bering Sea. Here it flows in a general counterclockwise direction. The southward flow along the Kamchatka peninsula is called the **Kamchatka Current** which feeds the southerly flowing Oyashio. Some water flows northward from the Bering Sea through the eastern side of the Bering Strait, into the Arctic Ocean.

The **South Equatorial Current**, extending in width between about 4°N latitude and 10°S, flows westward from South America to the western Pacific. After this current crosses the 180th meridian, the major part curves in a counterclockwise direction, entering the Coral Sea, and then curving more sharply toward the south along the east coast of Australia, where it is known as the **East Australian Current**. The East Australian Current is the weakest of the subtropical western boundary currents and separates from the Australian coast near 34°S. The path of the current from Australia to New Zealand is known as the **Tasman Front**, which marks the boundary between the warm water of the Coral Sea and the colder water of the Tasman Sea. The continuation of the East Australian Current east of New Zealand is the **East Auckland Current**. The East Auckland Current varies seasonally: in winter, it separates from the shelf and flows eastward, merging with the West Wind Drift, while in winter it follows the New Zealand shelf southward as the **East Cape Current** until it reaches Chatham Rise where it turns eastward, thence merging with the West Wind Drift.

Near the southern extremity of South America, most of this current flows eastward into the Atlantic, but part of it curves toward the left and flows generally northward along the west coast of South America as the **Peru Current** or **Humboldt Current**. Occasionally a set directly toward land is encountered. At about Cabo Blanco, where the coast falls away to the right, the current curves toward the left, past the Galapagos Islands, where it takes a westerly set and constitutes the major portion of the South Equatorial Current, thus completing the counterclockwise circulation of the South Pacific.

During the northern hemisphere summer, a weak northern branch of the South Equatorial Current, known as the **New Guinea Coastal Current**, continues on toward the west and northwest along both the southern and northeastern coasts of New Guinea. The southern part flows through Torres Strait, between New Guinea and Australia, into the Arafura Sea. Here, it gradually loses its identity, part of it flowing on toward the west as part of the South Equatorial Current of the Indian Ocean, and part of it following the coast of Australia and finally joining the easterly flowing West Wind Drift. The northern part of New Guinea Coastal Current both curves in a clockwise direction to help form the Pacific Equatorial Countercurrent and off Mindanao turns southward to form a southward flowing boundary current called the **Mindanao Current**. During the northern hemisphere winter, the New Guinea Coastal Current may reverse direction for a few months.

3208. Indian Ocean Currents

Indian Ocean currents follow generally the pattern of the Atlantic and Pacific but with differences caused principally by the monsoons, the more limited extent of water in the Northern Hemisphere, and by limited communication with the Pacific Ocean along the eastern boundary. During the northern hemisphere winter, the **North Equatorial Current** and **South Equatorial Current** flow toward the west, with the weaker, eastward **Equatorial Countercurrent** flowing between them, as in the Atlantic and Pacific (but somewhat south of the equator). But during the northern hemisphere summer, both the North Equatorial Current and the Equatorial Countercurrent are replaced by the **Southwest Monsoon Current**, which flows eastward and southeastward across the Arabian Sea and the Bay of Bengal. Near Sumatra, this current curves in a clockwise direction and flows westward, augmenting the South Equatorial Current, and setting up a clockwise circulation in the northern part of the Indian Ocean. Off the coast of Somalia, the **Somali Current** reverses direction during the northern hemisphere summer with northward currents reaching speeds of 5 knots or more. Twice a year, around May and November, westerly winds along the equator result in an eastward **Equatorial Jet** which feeds warm water towards Sumatra.

As the South Equatorial Current approaches the coast of Africa, it curves toward the southwest, part of it flowing through the Mozambique Channel between Madagascar and the mainland, and part flowing along the east coast of Madagascar. At the southern end of this island the two join to form the strong **Agulhas Current**, which is analogous to the Gulf Stream. This current, when opposed by strong winds from Southern Ocean storms, creates dangerously large seas.

South of South Africa, the Agulhas Current retroflects, and most of the flow curves sharply southward and then eastward to join the West Wind Drift; this junction is often marked by a broken and confused sea, made much worse by westerly storms. A small part of the Agulhas Current rounds the southern end of Africa and helps form the **Benguela Current**; occasionally, strong eddies are formed in the retroflection region and these too move into the Southeastern Atlantic.

The eastern boundary currents in the Indian Ocean are quite different from those found in the Atlantic and Pacific. The seasonally reversing **South Java Current** has strongest westward flow during August when monsoon winds are easterly and the Equatorial jet is inactive. Along the coast of Australia, a vigorous poleward flow, the **Leeuwin Current**, runs against the prevailing winds.

3209. Arctic Currents

The waters of the North Atlantic enter the Arctic Ocean between Norway and Svalbard. The currents flow easterly, north of Siberia, to the region of the Novosibirskiye Ostrova, where they turn northerly across the North Pole, and continue down the Greenland coast to form the **East Greenland Current**. On the American side of the Arctic basin, there is a weak, continuous clockwise flow centered in the vicinity of 80°N, 150°W. A current north through Bering Strait along the American coast is balanced by an outward southerly flow along the Siberian coast, which eventually becomes part of the **Kamchatka Current**. Each of the main islands or island groups in the Arctic, as far as is known, seems to have a clockwise nearshore circulation around it. The Barents Sea, Kara Sea, and Laptev Sea each have a weak counterclockwise circulation. A similar but weaker counterclockwise current system appears to exist in the East Siberian Sea.

OCEANIC CURRENT PHENOMENA

3210. Ocean Eddies And Rings

Eddies with horizontal diameters varying from 50-150 km have their own pattern of surface currents. These features may have either a warm or a cold core and currents flow around this core, either cyclonically for cold cores or anticyclonically for warm cores. The most intense of these features are called **rings** and are formed by the pinching off of meanders of western boundary currents such as the Gulf Stream. Maximum speed associated with these features is about 2 knots. Rings have also been observed to pinch off from the Agulhas retroflexion and to then drift to the northwest into the South Atlantic. Similarly, strong anticyclonic eddies are occasionally spawned by the loop current into the Western Gulf Mexico.

In general, mesoscale variability is strongest in the region of western boundary currents and in the Circumpolar Current. The strength of mesoscale eddies is greatly reduced at distances of 200-400 km from these strong boundary currents, because mean currents are generally weaker in these regions. The eddies may be sufficiently strong to reverse the direction of the surface currents.

3211. Undercurrents

At the equator and along some ocean boundaries, shallow undercurrents exist, flowing in a direction counter to that at the surface. These currents may affect the operation of submarines or trawlers. The most intense of these flows, called the Pacific **Equatorial Undercurrent**, is found at the equator in the Pacific. It is centered at a depth of 150m to the west of the Galapagos, is about 4 km wide, and eastward speeds of up to 1.5 m/s have been observed. Equatorial Undercurrents are also observed in the Atlantic and Indian Ocean, but they are somewhat weaker. In the Atlantic, the Equatorial Undercurrent is found to the east of 24°W and in the Indian Ocean, it appears to be seasonal.

Undercurrents also exist along ocean boundaries. They seem to be most ubiquitous at the eastern boundary of oceans. Here they are found at depths of 100-200m, may be 100 km wide, and have maximum speeds of 0.5 m/s.

3212. Ocean Currents And Climate

Many of the ocean currents exert a marked influence upon the climate of the coastal regions along which they flow. Thus, warm water from the Gulf Stream, continuing as the North Atlantic, Northeast Drift, and Irminger Currents, arrives off the southwest coast of Iceland, warming it to the extent that Reykjavik has a higher average winter temperature than New York City, far to the south. Great Britain and Labrador are about the same latitude, but the climate of Great Britain is much milder because of the relatively warm currents. The west coast of the United States is cooled in the summer by the California Current, and warmed in the winter by the Davidson Current. Partly as a result of this circulation, the range of monthly average temperature is comparatively small.

Currents exercise other influences besides those on temperature. The pressure pattern is affected materially, as air over a cold current contracts as it is cooled, and that over a warm current expands. As air cools above a cold ocean current, fog is likely to form. Frost smoke occurs over a warm current which flows into a colder region. Evaporation is greater from warm water than from cold water, adding to atmospheric moisture.

3213. Ocean Current Observations

Historically, our views of the surface circulation of the ocean have been shaped by reports of ocean currents provided by mariners. As mentioned at the start of this chapter, these observations consist of reports of the difference between the dead reckoning and the observed position of the vessel. These observations were routinely collected until the start of World War II.

Two observation systems are generally used for surface current studies. The first utilizes autonomous free-drifting

buoys which are tracked by satellite or relay their position via satellite. These buoys consist of either a spherical or cylindrical surface float which is about 0.5m in diameter with a drogue at a depth of about 35m. The second system utilizes acoustic Doppler current profilers. These profilers utilize hull mounted transducers, operate at a frequency of 150 kHz, and have pulse repetition rates of about 1 second. They can penetrate to about 300m, and, where water is shallower than this depth, track the bottom. Merchant and naval vessels are increasingly being outfitted with acoustic Doppler current profilers which, when operated with the Global Positioning System, provide accurate observations of currents.

CHAPTER 33

WAVES, BREAKERS AND SURF

OCEAN WAVES

3300. Introduction

Ocean Waves are the most widely observed phenomenon at sea, and possibly the least understood by the average seaman. More than any other single factor, ocean waves are likely to cause a navigator to change course or speed to avoid damage to ship and cargo. Wind-generated ocean waves have been measured at more than 100 feet high, and tsunamis, caused by earthquakes, far higher. A mariner with knowledge of basic facts concerning waves is able to use them to his advantage, avoid hazardous conditions, and operate with a minimum of danger if such conditions cannot be avoided. See Chapter 38, Weather Routing, for details on how to avoid areas of severe waves.

3301. Causes Of Waves

Waves on the surface of the sea are caused principally by wind, but other factors, such as submarine earthquakes, volcanic eruptions, and the tide, also cause waves. If a breeze of less than 2 knots starts to blow across smooth water, small wavelets called **ripples** form almost instantaneously. When the breeze dies, the ripples disappear as suddenly as they formed, the level surface being restored by surface tension of the water. If the wind speed exceeds 2 knots, more stable **gravity waves** gradually form, and progress with the wind.

While the generating wind blows, the resulting waves may be referred to as **sea**. When the wind stops or changes direction, waves that continue on without relation to local winds are called **swell**.

Unlike wind and current, waves are not deflected appreciably by the rotation of the earth, but move in the direction in which the generating wind blows. When this wind ceases, friction and spreading cause the waves to be reduced in height, or attenuated, as they move. However, the reduction takes place so slowly that swell often continues until it reaches some obstruction, such as a shore.

The Fleet Numerical Meteorology and Oceanography Center produces synoptic analyses and predictions of ocean wave heights using a spectral numerical model. The wave information consists of heights and directions for different periods and wavelengths. Verification of projected data has proven the model to be very good. Information from the model is provided to the U.S. Navy on a routine basis and is a vital input to the Optimum Track Ship Routing program.

3302. Wave Characteristics

Ocean waves are very nearly in the shape of an inverted cycloid, the figure formed by a point inside the rim of a wheel rolling along a level surface. This shape is shown in Figure 3302a. The highest parts of waves are called **crests**, and the intervening lowest parts, troughs. Since the crests are steeper and narrower than the troughs, the mean or still water level is a little lower than halfway between the crests and troughs. The vertical distance between trough and crest is called **wave height**, labeled H in Figure 3302a. The horizontal distance between successive crests, measured in the direction of travel, is called **wavelength**, labeled L. The time interval between passage of successive crests at a stationary point is called **wave period** (P). Wave height, length, and period depend upon a number of factors, such as the wind speed, the length of time it has blown, and its **fetch** (the straight distance it has traveled over the surface). Table 3302 indicates the relationship between wind speed, fetch, length of time the wind blows, wave height, and wave period in deep water.

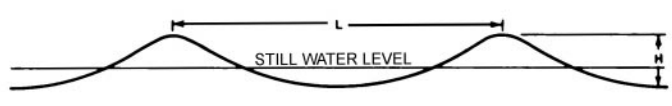


Figure 3302a. A typical sea wave

If the water is deeper than one-half the wavelength (L), this length in feet is theoretically related to period (P) in seconds by the formula:

$$L = 5.12\ P^2.$$

The actual value has been found to be a little less than this for swell, and about two-thirds the length determined by this formula for sea. When the waves leave the generating area and continue as free waves, the wavelength and period continue to increase, while the height decreases. The rate of change gradually decreases.

Fetch	BEAUFORT NUMBER																											Fetch
	3			4			5			6			7			8			9			10			11			
	T	H	P	T	H	P	T	H	P	T	H	P	T	H	P	T	H	P	T	H	P	T	H	P	T	H	P	
10	4.4	1.8	2.1	3.7	2.6	2.4	3.2	3.5	2.8	2.7	5.0	3.1	2.5	6.0	3.4	2.3	7.3	3.9	2.0	8.0	4.1	1.9	10.0	4.2	1.8	10.0	5.0	10
20	7.1	2.0	2.5	6.2	3.2	2.9	5.4	4.9	3.3	4.7	7.0	3.8	4.2	8.6	4.3	3.9	10.0	4.4	3.5	12.0	5.0	3.2	14.0	5.2	3.0	16.0	5.9	20
30	9.8	2.0	2.8	8.3	3.8	3.3	7.2	5.8	3.7	6.2	8.0	4.2	5.8	10.0	4.6	5.2	12.1	5.0	4.7	15.8	5.5	4.4	18.0	6.0	4.1	19.8	6.3	30
40	12.0	2.0	3.0	10.3	3.9	3.6	8.9	6.2	4.1	7.8	9.0	4.6	7.1	11.2	4.9	6.5	14.0	5.4	5.8	17.7	5.9	5.4	21.0	6.3	5.1	22.5	6.7	40
50	14.0	2.0	3.2	12.4	4.0	3.8	11.0	6.5	4.4	9.1	9.8	4.8	8.4	12.2	5.2	7.7	15.7	5.6	6.9	19.8	6.3	6.4	23.0	6.7	6.1	25.0	7.1	50
60	16.0	2.0	3.5	14.0	4.0	4.0	12.0	6.8	4.6	10.2	10.3	5.1	9.6	13.2	5.5	8.7	17.0	6.0	8.0	21.0	6.5	7.4	25.0	7.0	7.0	27.5	7.5	60
70	18.0	2.0	3.7	15.8	4.0	4.1	13.5	7.0	4.8	11.9	10.8	5.4	10.5	13.9	5.7	9.9	18.0	6.4	9.0	22.5	6.8	8.3	26.5	7.3	7.8	29.5	7.7	70
80	20.0	2.0	3.8	17.0	4.0	4.2	15.0	7.2	4.9	13.0	11.0	5.6	12.0	14.5	6.0	11.0	18.9	6.6	10.0	24.0	7.1	9.3	28.0	7.7	8.6	31.5	7.9	80
90	23.6	2.0	3.9	18.8	4.0	4.3	16.5	7.3	5.1	14.1	11.2	5.8	13.0	15.0	6.3	12.0	20.0	6.7	11.0	25.0	7.2	10.2	30.0	7.9	9.5	34.0	8.2	90
100	27.1	2.0	4.0	20.0	4.0	4.4	17.5	7.3	5.3	15.1	11.4	6.0	14.0	15.5	6.5	12.8	20.5	6.9	11.9	26.5	7.6	11.0	32.0	8.1	10.3	35.0	8.5	100
120	31.1	2.0	4.2	22.4	4.1	4.7	20.0	7.8	5.4	17.0	11.7	6.2	15.9	16.0	6.7	14.5	21.5	7.3	13.1	27.5	7.9	12.3	33.5	8.4	11.5	37.5	8.8	120
140	36.6	2.0	4.5	25.8	4.2	4.9	22.5	7.9	5.8	19.1	11.9	6.4	17.6	16.2	7.0	16.0	22.0	7.6	14.8	29.0	8.3	13.9	35.5	8.8	13.0	40.0	9.2	140
160	43.2	2.0	4.9	28.4	4.2	5.2	24.3	7.9	6.0	21.1	12.0	6.6	19.5	16.5	7.3	18.0	23.0	8.0	16.4	30.5	8.7	15.1	37.0	9.1	14.5	42.5	9.6	160
180	50.0	2.0	4.9	30.9	4.3	5.4	27.0	8.0	6.2	23.1	12.1	6.8	21.3	17.0	7.5	19.9	23.5	8.3	18.0	31.5	9.0	16.5	38.5	9.5	16.0	44.5	10.0	180
200				33.5	4.3	5.6	29.0	8.0	6.4	25.4	12.2	7.1	23.1	17.5	7.7	21.5	23.5	8.5	19.3	32.5	9.2	18.1	40.0	9.8	17.1	46.0	10.3	200
220				36.5	4.4	5.8	31.1	8.0	6.6	27.2	12.3	7.2	25.0	17.9	8.0	22.9	24.0	8.8	20.9	34.0	9.6	19.1	41.5	10.1	18.2	47.5	10.6	220
240				39.2	4.4	5.9	33.1	8.0	6.8	29.0	12.4	7.3	26.8	17.9	8.2	24.4	24.5	9.0	22.0	34.5	9.8	20.5	43.0	10.3	19.5	49.0	10.8	240
260				41.9	4.4	6.0	34.9	8.0	6.9	30.5	12.6	7.5	28.0	18.0	8.4	26.0	25.0	9.2	23.5	34.5	10.0	21.8	44.0	10.6	20.9	50.5	11.1	260
280				44.5	4.4	6.2	36.8	8.0	7.0	32.4	12.9	7.8	29.5	18.0	8.5	27.7	25.0	9.4	25.0	35.0	10.2	23.0	45.0	10.9	22.0	51.5	11.3	280
300				47.0	4.4	6.3	38.5	8.0	7.1	34.1	13.1	8.0	31.5	18.0	8.7	29.0	25.0	9.5	26.3	35.0	10.4	24.3	45.0	11.1	23.2	53.0	11.6	300
320							40.5	8.0	7.2	36.0	13.3	8.2	33.0	18.0	8.9	30.2	25.0	9.6	27.6	35.5	10.6	25.5	45.5	11.2	24.5	54.0	11.8	320
340							42.4	8.0	7.3	37.6	13.4	8.3	34.2	18.0	9.0	31.6	25.0	9.8	29.0	36.0	10.8	26.7	46.0	11.4	25.5	55.0	12.0	340
360							44.2	8.0	7.4	38.8	13.4	8.4	35.7	18.1	9.1	33.0	25.0	9.9	30.0	36.5	10.9	27.7	46.5	11.6	26.6	55.0	12.2	360
380							46.1	8.0	7.5	40.2	13.5	8.5	37.1	18.2	9.3	34.2	25.5	10.0	31.3	37.0	11.1	29.1	47.0	11.8	27.7	55.5	12.4	380
400							48.0	8.0	7.7	42.2	13.5	8.6	38.8	18.4	9.5	35.6	26.0	10.2	32.5	37.0	11.2	30.2	47.5	12.0	28.9	56.0	12.6	400
420							50.0	8.0	7.8	43.5	13.6	8.7	40.0	18.7	9.6	36.9	26.5	10.3	33.7	37.5	11.4	31.5	47.5	12.2	29.6	56.5	12.7	420
440							52.0	8.0	7.9	44.7	13.7	8.8	41.3	18.8	9.7	38.1	27.0	10.4	34.8	37.5	11.5	32.5	48.0	12.3	30.9	57.0	12.9	440
460							54.0	8.0	8.0	46.2	13.7	8.9	42.8	19.0	9.8	39.5	27.5	10.6	36.0	37.5	11.7	33.5	48.5	12.5	31.8	57.5	13.1	460
480							56.0	8.0	8.1	47.8	13.7	9.0	44.0	19.0	9.9	41.0	27.5	10.8	37.0	37.5	11.8	34.5	49.0	12.6	32.7	57.5	13.2	480
500							58.0	8.0	8.2	49.2	13.8	9.1	45.5	19.1	10.1	42.1	27.5	10.9	38.3	38.0	11.9	35.5	49.0	12.7	33.9	58.0	13.4	500
550										53.0	13.8	9.3	48.5	19.5	10.3	44.9	27.5	11.1	41.0	38.5	12.2	38.2	50.0	13.0	36.5	59.0	13.7	550
600										56.3	13.8	9.5	51.8	19.7	10.5	47.7	27.5	11.3	43.6	39.0	12.5	40.3	50.0	13.3	38.7	60.0	14.0	600
650													55.0	19.8	10.7	50.3	27.5	11.6	46.4	39.5	12.8	43.0	50.0	13.7	41.0	60.0	14.2	650
700													58.5	19.8	11.0	53.2	27.5	11.8	49.0	40.0	13.1	45.4	50.5	14.0	43.5	60.5	14.5	700
750																56.2	27.5	12.1	51.0	40.0	13.3	48.0	51.0	14.2	45.8	61.0	14.8	750
800																59.2	27.5	12.3	53.8	40.0	13.5	50.6	51.5	14.5	47.8	61.5	15.0	800
850																			56.2	40.0	13.8	52.5	52.0	14.6	50.0	62.0	15.2	850
900																			58.2	40.0	14.0	54.6	52.0	14.9	52.0	62.5	15.5	900
950																						57.2	52.0	15.1	54.0	63.0	15.7	950
1000																						59.3	52.0	15.3	56.3	63.0	16.0	1000

Table 3302. Minimum Time (T) in hours that wind must blow to form waves of H significant height (in feet) and P period (in secconds). Fetch in nautical miles.

The speed (S) of a free wave in deep water is nearly independent of its height or steepness. For swell, its relationship in knots to the period (P) in seconds is given by the formula

$$S = 3.03P.$$

The relationship for sea is not known.

The theoretical relationship between speed, wavelength, and period is shown in Figure 3302b. As waves continue on beyond the generating area, the period, wavelength, and speed remain the same. Because the waves of each period have different speeds they tend to sort themselves by periods as they move away from the generating area. The longer period waves move at a greater speed and move ahead. At great enough distances from a storm area the waves will have sorted themselves into sets based on period.

All waves are attenuated as they propagate but the short period waves attenuate faster, so that far from a storm only the longer waves remain.

The time needed for a wave system to travel a given distance is double that which would be indicated by the speed of individual waves. This is because each leading wave in succession gradually disappears and transfers its energy to following wave. The process occurs such that the whole wave *system* advances at a speed which is just half that of each individual wave. This process can easily be seen in the bow wave of a vessel. The speed at which the wave system advances is called **group velocity**.

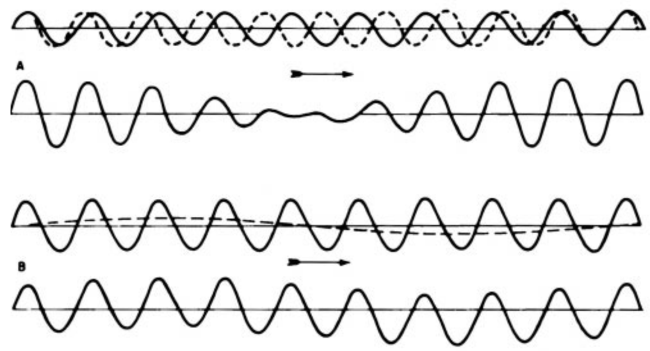


Figure 3302c. Interference. The upper part of A shows two waves of equal height and nearly equal length traveling in the same direction. The lower part of A shows the resulting wave pattern. In B similar information is shown for short waves and long swell.

Because of the existence of many independent wave systems at the same time, the sea surface acquires a complex and irregular pattern. Since the longer waves overrun the shorter ones, the resulting interference adds to the complexity of the pattern. The process of interference, illustrated in Figure 3302c, is duplicated many times in the sea; it is the principal reason that successive waves are

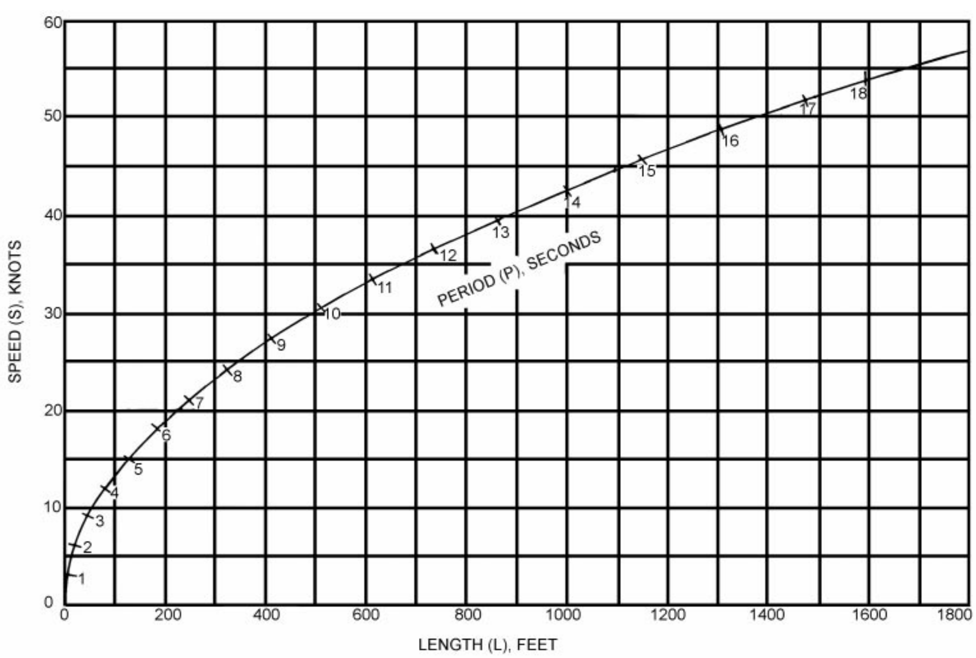


Figure 3302b. Relationship between speed, length, and period of waves in deep water, based upon the theoretical relationship between period and length.

not of the same height. The irregularity of the surface may be further accentuated by the presence of wave systems crossing at an angle to each other, producing peak-like rises.

In reporting average wave heights, the mariner has a tenency to neglect the lower ones. It has been found that the reported value is about the average for the highest one-third. This is sometimes called the "significant" wave height. The approximate relationship between this height and others, is as follows:

Wave	*Relative height*
Average	0.64
Significant	1.00
Highest 10 percent	1.29
Highest	1.87

3303. Path Of Water Particles In A Wave

As shown in Figure 3303, a particle of water on the surface of the ocean follows a somewhat circular orbit as a wave passes, but moves very little in the direction of motion of the wave. The common wave producing this action is called an **oscillatory wave**. As the crest passes, the particle moves forward, giving the water the appearance of moving with the wave. As the trough passes, the motion is in the opposite direction. The radius of the circular orbit decreases with depth, approaching zero at a depth equal to about half the wavelength. In shallower water the orbits become more elliptical, and in very shallow water the vertical motion disappears almost completely.

Since the speed is greater at the top of the orbit than at the bottom, the particle is not at exactly its original point following passage of a wave, but has moved slightly in the wave's direction of motion. However, since this advance is small in relation to the vertical displacement, a floating object is raised and lowered by passage of a wave, but moved little from its original position. If this were not so, a slow moving vessel might experience considerable difficulty in making way against a wave train. In Figure 3303 the forward displacement is greatly exaggerated.

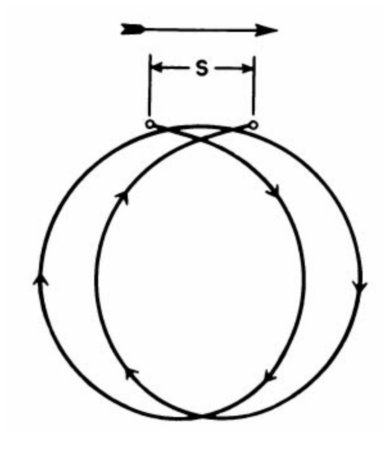


Figure 3303. Orbital motion and displacement, s, of a particle on the surface of deep water during two wave periods.

3304. Effects Of Currents On Waves

A following current increases wavelengths and decreases wave heights. An opposing current has the opposite effect, decreasing the length and increasing the height. This effect can be dangerous in certain areas of the world where a stream current opposes waves generated by severe weather. An example of this effect is off the Coast of South Africa, where the Agulhas current is often opposed by westerly storms, creating steep, dangerous seas. A strong opposing current may cause the waves to break, as in the case of **overfalls** in tidal currents. The extent of wave alteration is dependent upon the ratio of the still-water wave speed to the speed of the current.

Moderate ocean currents running at oblique angles to wave directions appear to have little effect, but strong tidal currents perpendicular to a system of waves have been observed to completely destroy them in a short period of time.

3305. The Effect Of Ice On Waves

When ice crystals form in seawater, internal friction is greatly increased. This results in smoothing of the sea surface. The effect of pack ice is even more pronounced. A vessel following a lead through such ice may be in smooth water even when a gale is blowing and heavy seas are beating against the outer edge of the pack. Hail or torrential rain is also effective in flattening the sea, even in a high wind.

3306. Waves And Shallow Water

When a wave encounters shallow water, the movement of the water is restricted by the bottom, resulting in reduced wave speed. In deep water wave speed is a function of period. In shallow water, the wave speed becomes a function of depth. The shallower the water, the slower the wave speed. As the wave speed slows, the period remains the same, so the wavelength becomes shorter. Since the energy in the waves remains the same, the shortening of wavelengths results in increased heights. This process is called **shoaling**. If the wave approaches a shallow area at an angle, each part is slowed successively as the depth decreases. This causes a change in direction of motion, or **refraction**, the wave tending to change direction parallel to the depth curves. The effect is similar to the refraction of light and other forms of radiant energy.

As each wave slows, the next wave behind it, in deeper water, tends to catch up. As the wavelength decreases, the height generally becomes greater. The lower part of a wave, being nearest the bottom, is slowed more than the top. This

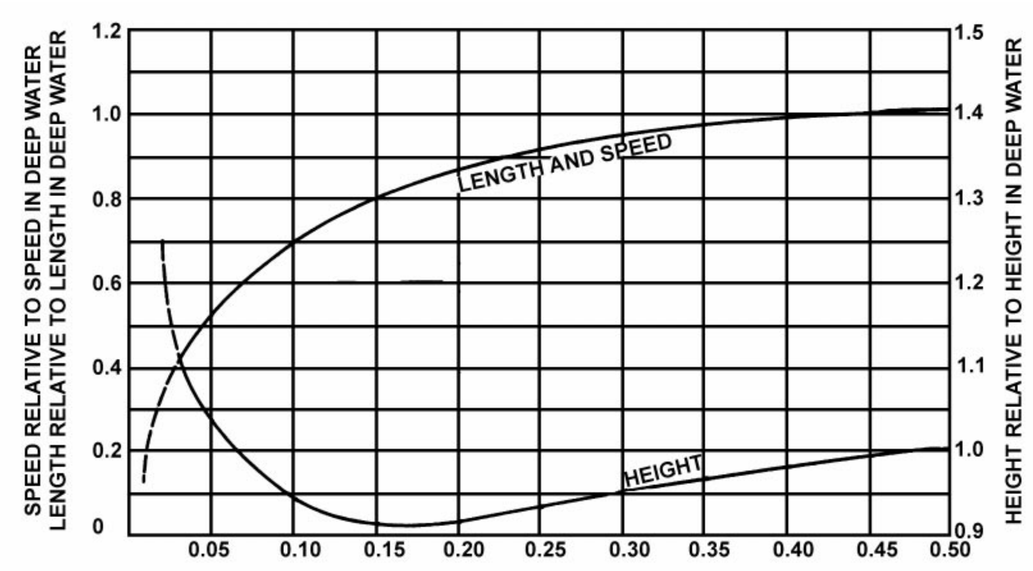


Figure 3306. Alteration of the characteristics of waves crossing a shoal.

may cause the wave to become unstable, the faster-moving top falling forward or breaking. Such a wave is called a **breaker**, and a series of breakers is **surf**.

Swell passing over a shoal but not breaking undergoes a decrease in wavelength and speed, and an increase in height, which may be sudden and dramatic, depending on the steepness of the seafloor's slope. This **ground swell** may cause heavy rolling if it is on the beam and its period is the same as the period of roll of a vessel, even though the sea may appear relatively calm. It may also cause a **rage sea**, when the swell waves encounter water shoal enough to make them break. Rage seas are dangerous to small craft, particularly approaching from seaward, as the vessel can be overwhelmed by enormous breakers in perfectly calm weather. The swell waves, of course, may have been generated hundreds of miles away. In the open ocean they are almost unnoticed due to their very long period and wavelength. Figure 3306 illustrates the approximate alteration of the characteristics of waves as they cross a shoal.

3307. Energy Of Waves

The potential energy of a wave is related to the vertical distance of each particle from its still-water position. Therefore potential energy moves with the wave. In contrast, the kinetic energy of a wave is related to the speed of the particles, distributed evenly along the entire wave.

The amount of kinetic energy in a wave is tremendous. A 4-foot, 10-second wave striking a coast expends more than 35,000 horsepower per mile of beach. For each 56 miles of coast, the energy expended equals the power generated at Hoover Dam. An increase in temperature of the water in the relatively narrow surf zone in which this energy is expended would seem to be indicated, but no pronounced increase has been measured. Apparently, any heat that may be generated is dissipated to the deeper water beyond the surf zone.

3308. Wave Measurement Aboard Ship

With suitable equipment and adequate training, reliable measurements of the height, length, period, and speed of waves can be made. However, the mariner's estimates of height and length often contain relatively large errors. There is a tendency to underestimate the heights of low waves, and overestimate the heights of high ones. There are numerous accounts of waves 75 to 80 feet high, or even higher, although waves more than 55 feet high are very rare. Wavelength is usually underestimated. The motions of the vessel from which measurements are made contribute to such errors.

Height. Measurement of wave height is particularly difficult. A microbarograph can be used if the wave is long enough or the vessel small enough to permit the vessel to ride from crest to trough. If the waves are approaching from dead ahead or dead astern, this requires a wavelength at least twice the length of the vessel. For most accurate results the instrument should be placed at the center of roll and pitch, to minimize the effects of these motions. Wave height can often be estimated with reasonable accuracy by comparing it with freeboard of the vessel. This is less accurate as wave height and vessel motion increase. If a point of observation can be found at which the top of a wave is in line with the horizon when the observer is in the trough, the wave height is equal to height of eye. However, if the vessel is rolling or pitching, this height at the moment of observation may be difficult to determine. The highest wave ever reliably reported was 112 feet observed from the USS Ramapo in 1933.

Length. The dimensions of the vessel can be used to determine wavelength. Errors are introduced by perspective and disturbance of the wave pattern by the vessel. These errors are minimized if observations are made from maximum height. Best results are obtained if the sea is from dead ahead or dead astern.

Period. If allowance is made for the motion of the vessel, wave period can be determined by measuring the interval between passages of wave crests past the observer. The relative motion of the vessel can be eliminated by timing the passage of successive wave crests past a patch of foam or a floating object at some distance from the vessel. Accuracy of results can be improved by averaging several observations.

Speed. Speed can be determined by timing the passage of the wave between measured points along the side of the ship, if corrections are applied for the direction of travel for the wave and the speed of the ship.

The length, period, and speed of waves are interrelated by the relationships indicated previously. There is no definite mathematical relationship between wave height and length, period, or speed.

3309. Tsunamis

Tsunamis are ocean waves produced by sudden, large-scale motion of a portion of the ocean floor or the shore, such as a volcanic eruption, earthquake (sometimes called seaquake if it occurs at sea), or landslide. If they are caused by a submarine earthquake, they are usually called **seismic sea waves**. The point directly above the disturbance, at which the waves originate, is called the **epicenter**. Either a tsunami or a storm tide that overflows the land is popularly called a **tidal wave**, although it bears no relation to the tide.

If a volcanic eruption occurs below the surface of the sea, the escaping gases cause a quantity of water to be pushed upward in the shape of a dome. The same effect is caused by the sudden rising of a portion of the bottom. As this water settles back, it creates a wave which travels at high speed across the surface of the ocean.

Tsunamis are a series of waves. Near the epicenter, the first wave may be the highest. At greater distances, the highest wave usually occurs later in the series, commonly between the third and the eighth wave. Following the maximum, they again become smaller, but the tsunami may be detectable for several days.

In deep water the wave height of a tsunami is probably never greater than 2 or 3 feet. Since the wavelength is usually considerably more than 100 miles, the wave is not conspicuous at sea. In the Pacific, where most tsunamis occur, the wave period varies between about 15 and 60 minutes, and the speed in deep water is more than 400 knots. The approximate speed can be computed by the formula:

$$S = 0.6\sqrt{gd} = 3.4\sqrt{d}\Delta\delta\gamma\Gamma$$

where S is the speed in knots, g is the acceleration due to gravity (32.2 feet per second per second), and d is the depth of water in feet. This formula is applicable to any wave in water having a depth of less than half the wavelength. For most ocean waves it applies only in shallow water, because of the relatively short wavelength.

When a tsunami enters shoal water, it undergoes the same changes as other waves. The formula indicates that speed is proportional to depth of water. Because of the great speed of a tsunami when it is in relatively deep water, the slowing is relatively much greater than that of an ordinary wave crested by wind. Therefore, the increase in height is also much greater. The size of the wave depends upon the nature and intensity of the disturbance. The height and destructiveness of the wave arriving at any place depends upon its distance from the epicenter, topography of the ocean floor, and the coastline. The angle at which the wave arrives, the shape of the coastline, and the topography along the coast and offshore, all have an effect. The position of the shore is also a factor, as it may be sheltered by intervening land, or be in a position where waves have a tendency to converge, either because of refraction or reflection, or both.

Tsunamis 50 feet in height or higher have reached the shore, inflicting widespread damage. On April 1, 1946, seismic sea waves originating at an epicenter near the Aleutians, spread over the entire Pacific. Scotch Cap Light on Unimak Island, 57 feet above sea level, was completely destroyed. Traveling at an average speed of 490 miles per hour, the waves reached the Hawaiian Islands in 4 hours and 34 minutes, where they arrived as waves 50 feet above the high water level, and flooded a strip of coast more than 1,000 feet wide at some places. They left a death toll of 173 and property damage of $25 million. Less destructive waves reached the shores of North and South America, as well as Australia, 6,700 miles from the epicenter.

After this disaster, a tsunami warning system was set up in the Pacific, even though destructive waves are relatively rare (averaging about one in 20 years in the Hawaiian Islands). This system monitors seismic disturbances throughout the Pacific basin and predicts times and heights of tsunamis. Warnings are immediately sent out if a disturbance is detected.

In addition to seismic sea waves, earthquakes below the surface of the sea may produce a longitudinal wave that travels upward at the speed of sound. When a ship encounters such a wave, it is felt as a sudden shock which may be so severe that the crew thinks the vessel has struck bottom.

3310. Storm Tides

In relatively tideless seas like the Baltic and Mediterranean, winds cause the chief fluctuations in sea level. Elsewhere, the astronomical tide usually masks these variations. However, under exceptional conditions, either severe extra-tropical storms or tropical cyclones can produce changes in sea level that exceed the normal range of tide. Low sea level is of little concern except to shipping, but a rise above ordinary high-water mark, particularly when it is accompanied by high waves, can result in a catastrophe.

Although, like tsunamis, these storm tides or storm

surges are popularly called tidal waves, they are not associated with the tide. They consist of a single wave crest and hence have no period or wavelength.

Three effects in a storm induce a rise in sea level. The first is wind stress on the sea surface, which results in a piling-up of water (sometimes called "wind set-up"). The second effect is the convergence of wind-driven currents, which elevates the sea surface along the convergence line. In shallow water, bottom friction and the effects of local topography cause this elevation to persist and may even intensify it. The low atmospheric pressure that accompanies severe storms causes the third effect, which is sometimes referred to as the "inverted barometer." An inch of mercury is equivalent to about 13.6 inches of water, and the adjustment of the sea surface to the reduced pressure can amount to several feet at equilibrium.

All three of these causes act independently, and if they happen to occur simultaneously, their effects are additive. In addition, the wave can be intensified or amplified by the effects of local topography. Storm tides may reach heights of 20 feet or more, and it is estimated that they cause three-fourths of the deaths attributed to hurricanes.

3311. Standing Waves And Seiches

Previous articles in this chapter have dealt with progressive waves which appear to move regularly with time. When two systems of progressive waves having the same period travel in opposite directions across the same area, a series of **standing waves** may form. These appear to remain stationary.

Another type of standing wave, called a **seiche**, sometimes occurs in a confined body of water. It is a long wave, usually having its crest at one end of the confined space, and its trough at the other. Its period may be anything from a few minutes to an hour or more, but somewhat less than the tidal period. Seiches are usually attributed to strong winds or differences in atmospheric pressure.

3312. Tide Waves

There are, in general, two regions of high tide separated by two regions of low tide, and these regions move progressively westward around the earth as the moon revolves in its orbit. The high tides are the crests of these tide waves, and the low tides are the troughs. The wave is not noticeable at sea, but becomes apparent along the coasts, particularly in funnel-shaped estuaries. In certain river mouths, or estuaries of particular configuration, the incoming wave of high water overtakes the preceding low tide, resulting in a high-crested, roaring wave which progresses upstream in a surge called a **bore**.

3313. Internal Waves

Thus far, the discussion has been confined to waves on the surface of the sea, the boundary between air and water. Internal waves, or boundary waves, are created below the surface, at the boundaries between water strata of different densities. The density differences between adjacent water strata in the sea are considerably less than that between sea and air. Consequently, internal waves are much more easily formed than surface waves, and they are often much larger. The maximum height of wind waves on the surface is about 60 feet, but internal wave heights as great as 300 feet have been encountered.

Internal waves are detected by a number of observations of the vertical temperature distribution, using recording devices such as the bathythermograph. They have periods as short as a few minutes, and as long as 12 or 24 hours, these greater periods being associated with the tides.

A slow-moving ship, operating in a freshwater layer having a depth approximating the draft of the vessel, may produce short-period internal waves. This may occur off rivers emptying into the sea, or in polar regions in the vicinity of melting ice. Under suitable conditions, the normal propulsion energy of the ship is expended in generating and maintaining these internal waves and the ship appears to "stick" in the water, becoming sluggish and making little headway. The phenomenon, known as **dead water**, disappears when speed is increased by a few knots.

The full significance of internal waves has not yet been determined, but it is known that they may cause submarines to rise and fall like a ship at the surface, and they may also affect sound transmission in the sea.

3314. Waves And Ships

The effects of waves on a ship vary considerably with the type of ship, its course and speed, and the condition of the sea. A short vessel has a tendency to ride up one side of a wave and down the other side, while a larger vessel may tend to ride through the waves on an even keel. If the waves are of such length that the bow and stern of a vessel are alternately riding in successive crests and troughs, the vessel is subject to heavy sagging and hogging stresses, and under extreme conditions may break in two. A change of heading may reduce the danger. Because of the danger from sagging and hogging, a small vessel is sometimes better able to ride out a storm than a large one.

If successive waves strike the side of a vessel at the same phase of successive rolls, relatively small waves can cause heavy rolling. The same effect, if applied to the bow or stern in time with the natural period of pitch, can cause heavy pitching. A change of either heading or speed can quickly reduce the effect.

A wave having a length twice that of a ship places that ship in danger of falling off into the trough of the sea, particularly if it is a slow-moving vessel. The effect is especially pronounced if the sea is broad on the bow or broad on the quarter. An increase of speed reduces the hazard.

3315. Using Oil To Calm Breaking Waves

Historically oil was effective in modifying the effects of breaking waves, and was useful to vessels when lowering or hoisting boats in rough weather. Its effect was greatest in

deep water, where a small quantity sufficed if the oil were made to spread to windward of the vessel.

Environmental concerns have led to this procedure being discontinued.

BREAKERS AND SURF

3316. Refraction

As explained previously, waves are slowed in shallow water, causing refraction if the waves approach the beach at an angle. Along a perfectly straight beach, with uniform shoaling, the wave fronts tend to become parallel to the shore. Any irregularities in the coastline or bottom contours, however, affect the refraction, causing irregularities. In the case of a ridge perpendicular to the beach, for instance, the shoaling is more rapid, causing greater refraction towards the ridge. The waves tend to align themselves with the bottom contours. Waves on both sides of the ridge have a component of motion toward the ridge. This convergence of wave energy toward the ridge causes an increase in wave or breaker height. A submarine canyon or valley perpendicular to the beach, on the other hand, produces divergence, with a decrease in wave or breaker height. These effects are illustrated in Figure 3316. Bends in the coast line have a similar effect, convergence occurring at a point, and divergence if the coast is concave to the sea. Points act as focal areas for wave energy and experience large breakers. Concave bays have small breakers because the energy is spread out as the waves approach the beach.

Under suitable conditions, currents also cause refraction. This is of particular importance at entrances of tidal estuaries. When waves encounter a current running in the opposite direction, they become higher and shorter. This results in a choppy sea, often with breakers. When waves move in the same direction as current, they decrease in height, and become longer. Refraction occurs when waves encounter a current at an angle.

Refraction diagrams, useful in planning amphibious operations, can be prepared with the aid of nautical charts or aerial photographs. When computer facilities are available, computer programs can be used to produce refraction diagrams quickly and accurately.

3317. Classes Of Breakers

In deep water, swell generally moves across the surface as somewhat regular, smooth undulations. When shoal water is reached, the wave period remains the same, but the speed decreases. The amount of decrease is negligible until the depth of water becomes about one-half the wavelength, when the waves begin to “feel” bottom. There is a slight decrease in wave height, followed by a rapid increase, if the waves are traveling perpendicular to a straight coast with a uniformly sloping bottom. As the waves become higher and

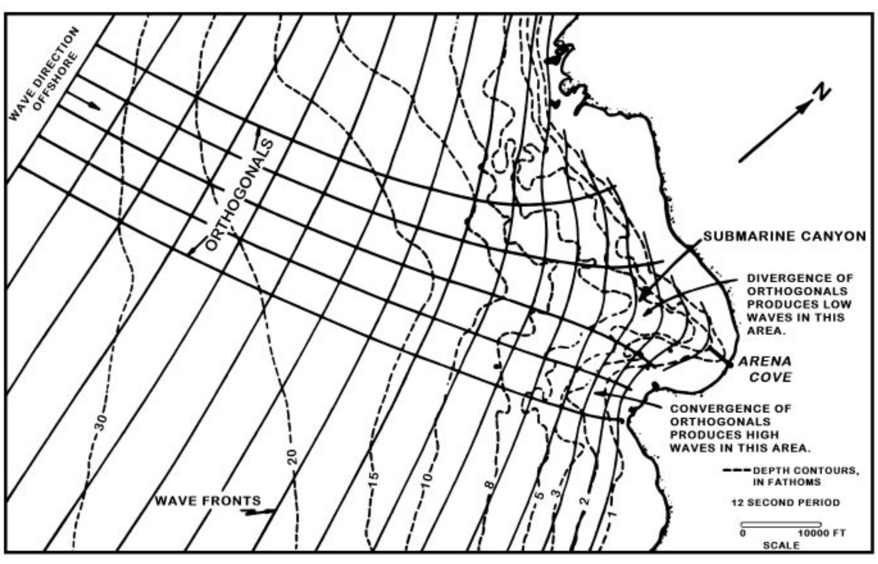


Figure 3316. The effect of bottom topography in causing wave convergence and wave divergence.
Courtesy of Robert L. Wiegel, Council on Wave Research, University of Californiia.

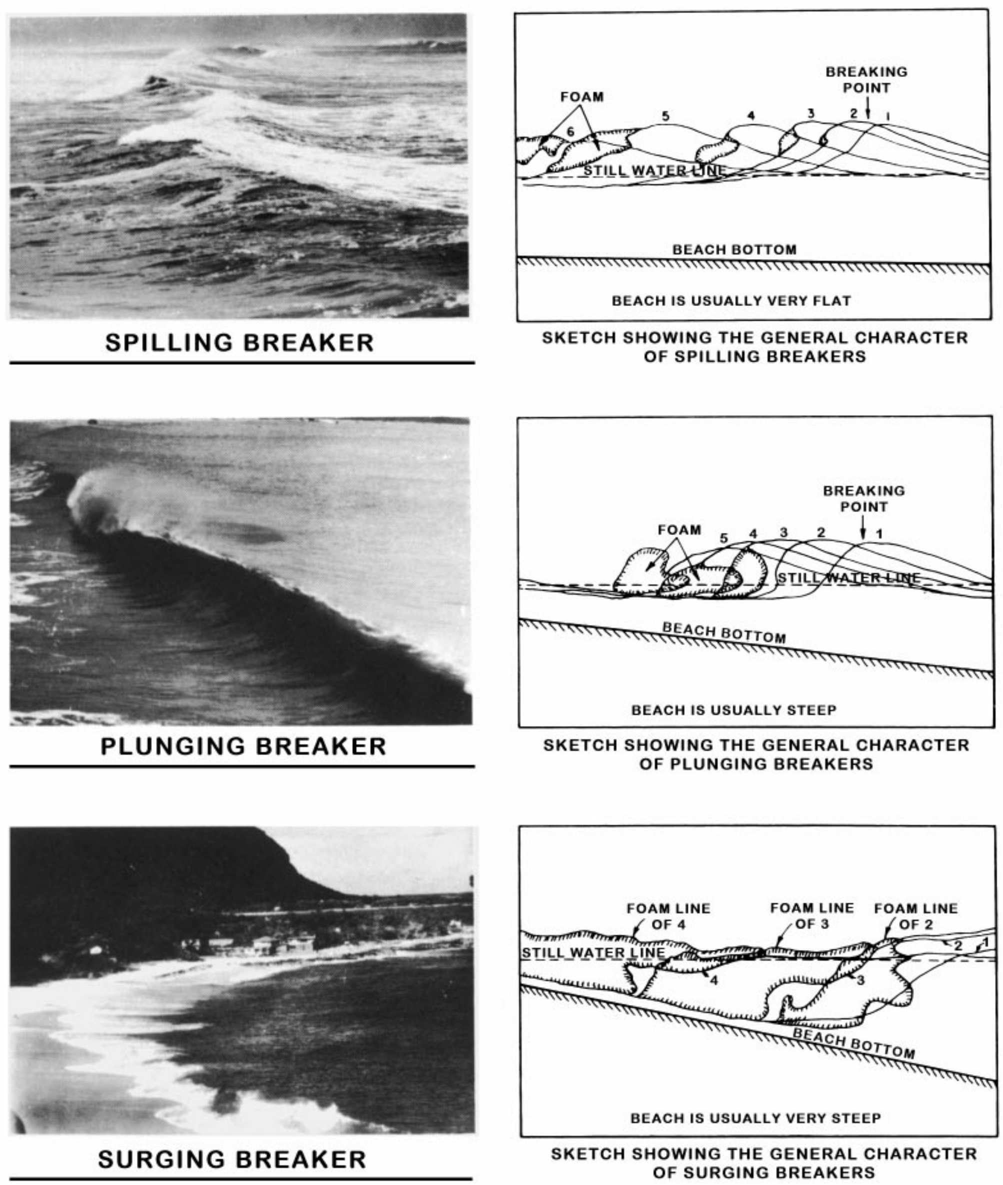


Figure 3317. The three types of breakers.
Courtesy of Robert L. Wiegel, Council on Wave Research, University of California.

shorter, they also become steeper, and the crest narrows. When the speed of the crest becomes greater than that of the wave, the front face of the wave becomes steeper than the rear face. This process continues at an accelerating rate as the depth of water decreases. If the wave becomes too unstable, it topples forward to form a breaker.

There are three general classes of breakers. A **spilling breaker** breaks gradually over a considerable distance. A **plunging breaker** tends to curl over and break with a single crash. A **surging breaker** peaks up, but surges up the beach without spilling or plunging. It is classed as a breaker even though it does not actually break. The type of breaker which forms is determined by the steepness of the beach and the steepness of the wave before it reaches shallow water, as illustrated in Figure 3317.

Long waves break in deeper water, and have a greater breaker height. A steep beach also increases breaker height. The height of breakers is less if the waves approach the beach at an acute angle. With a steeper beach slope there is greater tendency of the breakers to plunge or surge. Following the uprush of water onto a beach after the breaking of a wave, the seaward backrush occurs. The returning water is called **backwash**. It tends to further slow the bottom of a wave, thus increasing its tendency to break. This effect is

greater as either the speed or depth of the backwash increases. The still water depth at the point of breaking is approximately 1.3 times the average breaker height.

Surf varies with both position along the beach and time. A change in position often means a change in bottom contour, with the refraction effects discussed before. At the same point, the height and period of waves vary considerably from wave to wave. A group of high waves is usually followed by several lower ones. Therefore, passage through surf can usually be made most easily immediately following a series of higher waves.

Since surf conditions are directly related to height of the waves approaching a beach, and to the configuration of the bottom, the state of the surf at any time can be predicted if one has the necessary information and knowledge of the principles involved. Height of the sea and swell can be predicted from wind data, and information on bottom configuration can sometimes be obtained from the largest scale nautical chart. In addition, the area of lightest surf along a beach can be predicted if details of the bottom configuration are available. Surf predictions may, however, be significantly in error due to the presence of swell from unknown storms hundreds of miles away.

3318. Currents In The Surf Zone

In and adjacent to the surf zone, currents are generated by waves approaching the bottom contours at an angle, and by irregularities in the bottom.

Waves approaching at an angle produce a **longshore current** parallel to the beach, inside of the surf zone. Longshore currents are most common along straight beaches. Their speeds increase with increasing breaker height, decreasing wave period, increasing angle of breaker line with the beach, and increasing beach slope. Speed seldom exceeds 1 knot, but sustained speeds as high as 3 knots have been recorded. Longshore currents are usually constant in direction. They increase the danger of landing craft broaching to.

Where the bottom is sandy a good distance offshore, one or more **sand bars** typically form. The innermost bar will break in even small waves, and will isolate the longshore current. The second bar, if one forms, will break only in heavier weather, and the third, if present, only in storms. It is possible to move parallel to the coast in small craft in relatively deep water in the area between these bars, between the lines of breakers.

3319. Rip Currents

As explained previously, wave fronts advancing over nonparallel bottom contours are refracted to cause convergence or divergence of the energy of the waves. Energy concentrations in areas of convergence form barriers to the returning backwash, which is deflected along the beach to areas of less resistance. Backwash accumulates at weak points, and returns seaward in concentrations, forming **rip currents** through the surf. At these points the large volume of returning water has a retarding effect upon the incoming waves, thus adding to the condition causing the rip current. The waves on one or both sides of the rip, having greater energy and not being retarded by the concentration of backwash, advance faster and farther up the beach. From here, they move along the beach as feeder currents. At some point of low resistance, the water flows seaward through the surf, forming the neck of the rip current. Outside the breaker line the current widens and slackens, forming the head. The various parts of a rip current are shown in Figure 3319.

Rip currents may also be caused by irregularities in the beach face. If a beach indentation causes an uprush to advance farther than the average, the backrush is delayed and this in turn retards the next incoming foam line (the front of a wave as it advances shoreward after breaking) at that point. The foam line on each side of the retarded point continues in its advance, however, and tends to fill in the retarded area, producing a rip current.

Rip currents are dangerous for swimmers, but may provide a clear path to the beach for small craft, as they tend to scour out the bottom and break through any sand bars that

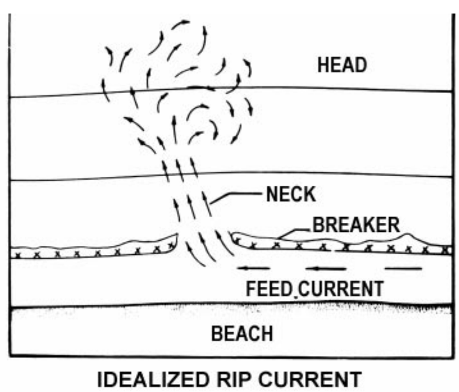


Figure 3319. A rip current (left) and a diagram of its parts (right).
Courtesy of Robert L. Wiegel, Council on Wave Research, University of California.

have formed. Rip currents also change location over time as conditions change.

3320. Beach Sediments

In the surf zone, large amounts of sediment are suspended in the water. When the water's motion decreases, the sediments settle to the bottom. The water motion can be either waves or currents. Promontories or points are rocky because the large breakers scour the points and small sediments are suspended in the water and carried away. Bays tend to have sandy beaches because of the smaller waves.

In the winter when storms create large breakers and surf, the waves erode beaches and carry the particles offshore where offshore sand bars form; sandy beaches tend to be narrower in stormy seasons. In the summer the waves gradually move the sand back to the beaches and the offshore sand bars decrease; then sandy beaches tend to be wider.

Longshore currents move large amounts of sand along the coast. These currents deposit sand on the upcurrent side of a jetty or pier, and erode the beach on the downcurrent side. Groins are sometime built to impede the longshore flow of sediments and preserve beaches for recreational use. As with jetties, the downcurrent side of each groin will have the best water for approaching the beach.

CHAPTER 34

ICE IN THE SEA

INTRODUCTION

3400. Ice And The Navigator

Sea ice has posed a problem to the polar navigator since antiquity. During a voyage from the Mediterranean to England and Norway sometime between 350 BC and 300 BC, Pytheas of Massalia sighted a strange substance which he described as “neither land nor air nor water” floating upon and covering the northern sea over which the summer sun barely set. Pytheas named this lonely region Thule, hence Ultima Thule (farthest north or land’s end). Thus began over 20 centuries of polar exploration.

Ice is of direct concern to the navigator because it restricts and sometimes controls his movements; it affects his dead reckoning by forcing frequent and sometimes inaccurately determined changes of course and speed; it affects his piloting by altering the appearance or obliterating the features of landmarks; it hinders the establishment and maintenance of aids to navigation; it affects his use of electronics by affecting propagation of radio waves; it produces changes in surface features and in radar returns from these features; it affects celestial navigation by altering the refraction and obscuring the horizon and celestial bodies either directly or by the weather it influences, and it affects charts by introducing several plotting problems.

Because of his direct concern with ice, the prospective polar navigator must acquaint himself with its nature and extent in the area he expects to navigate. In addition to this volume, books, articles, and reports of previous polar operations and expeditions will help acquaint the polar navigator with the unique conditions at the ends of the earth.

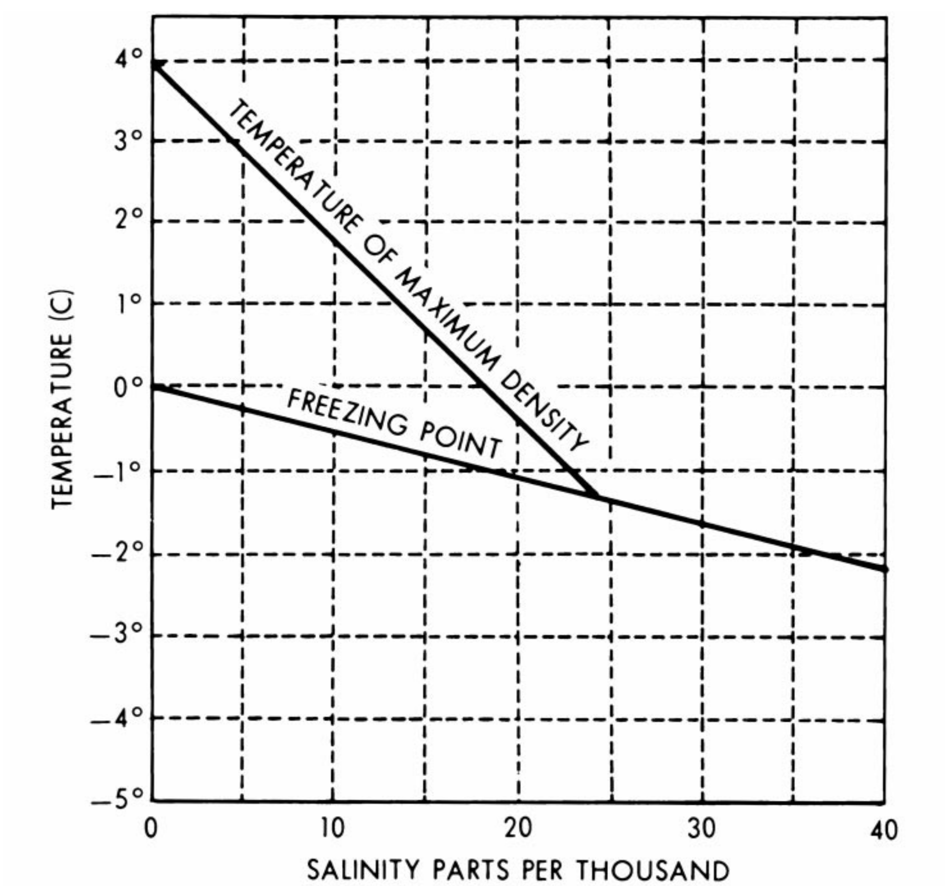


Figure 3401. Relationship between temperature of maximum density and freezing point for water of varying salinity.

3401. Formation Of Ice

As it cools, water contracts until the temperature of maximum density is reached. Further cooling results in expansion. The maximum density of fresh water occurs at a temperature of 4.0°C, and freezing takes place at 0°C. The addition of salt lowers both the temperature of maximum density and, to a lesser extent, that of freezing. These relationships are shown in Figure 3401. The two lines meet at a salinity of 24.7 parts per thousand, at which maximum density occurs at the freezing temperature of –1.3°C. At this and greater salinities, the temperature of maximum density of sea water is coincident with the freezing point temperature, i. e., the density increases as the temperature gets colder. At a salinity of 35 parts per thousand, the approximate average for the oceans, the freezing point is –1.88°C.

As the density of surface seawater increases with decreasing temperature, convective density-driven currents are induced bringing warmer, less dense water to the surface. If the polar seas consisted of water with constant salinity, the entire water column would have to be cooled to the freezing point in this manner before ice would begin to form. This is not the case, however, in the polar regions where the vertical salinity distribution is such that the surface waters are underlain at shallow depth by waters of higher salinity. In this instance density currents form a shallow mixed layer which subsequently cannot mix with the deep layer of warmer but saltier water. Ice will then begin forming at the water surface when density currents cease and the surface water reaches its freezing point. In shoal water, however, the mixing process can be sufficient to extend the freezing temperature from the surface to the bottom. Ice crystals can, therefore, form at any depth in this case. Because of their decreased density, they tend to rise to the surface, unless they form at the bottom and attach themselves there. This ice, called anchor ice, may continue to grow as additional ice freezes to that already formed.

3402. Land Ice

Ice of land origin is formed on land by the freezing of freshwater or the compacting of snow as layer upon layer adds to the pressure on that beneath.

Under great pressure, ice becomes slightly plastic, and is forced downward along an inclined surface. If a large area is relatively flat, as on the Antarctic plateau, or if the outward flow is obstructed, as on Greenland, an **ice cap** forms and remains throughout the year. The thickness of these ice caps ranges from nearly 1 kilometer on Greenland to as much as 4.5 kilometers on the Antarctic Continent. Where ravines or mountain passes permit flow of the ice, a **glacier** is formed. This is a mass of snow and ice which continuously flows to lower levels, exhibiting many of the characteristics of rivers of water. The flow may be more than 30 meters per day, but is generally much less. When a glacier reaches a comparatively level area, it spreads out. When a glacier flows into the sea, the buoyant force of the water breaks off pieces from time to time, and these float away as **icebergs**. Icebergs may be described as dome shaped, sloping or pinnacled (Figure 3402a), tabular (Figure 3402b), glacier, or weathered.

A floating iceberg seldom melts uniformly because of lack of uniformity in the ice itself, differences in the temperature above and below the waterline, exposure of one side to the sun, strains, cracks, mechanical erosion, etc. The inclusion of rocks, silt, and other foreign matter further accentuates the differences. As a result, changes in equilibrium take place, which may cause the berg to periodically tilt or capsize. Parts of it may break off or **calve**, forming separate smaller bergs. A relatively large piece of floating ice, generally extending 1 to 5 meters above the sea surface and normally about 100 to 300 square meters in area, is called a **bergy bit**. A smaller piece of ice large enough to inflict serious damage to a vessel is called a **growler** because of the noise it sometimes makes as it bobs up and down in the sea. Growlers extend less than 1 meter above the sea surface and normally occupy an area of about 20 square meters. Bergy bits and growlers are usually pieces calved from icebergs, but they may be the remains of a mostly melted iceberg.

The principal danger from icebergs is their tendency to break or capsize. Soon after a berg is calved, while remaining in far northern waters, 60–80% of its bulk is submerged. But as the berg drifts into warmer waters, the underside can sometimes melt faster than the exposed portion, especially in very cold weather. As the mass of the submerged portion deteriorates, the berg becomes increasingly unstable, and it will eventually roll over. Icebergs that have not yet capsized have a jagged and possibly dirty appearance. A recently capsized berg will be smooth, clean, and curved in appearance. Previous waterlines at odd angles can sometimes be seen after one or more capsizings.

The stability of a berg can sometimes be noted by its reaction to ocean swells. The livelier the berg, the more unstable it is. It is extremely dangerous for a vessel to approach an iceberg closely, even one which appears stable, because in addition to the danger from capsizing, unseen cracks can cause icebergs to split in two or calve off large chunks.

Another danger is from underwater extensions, called **rams**, which are usually formed due to melting or erosion above the waterline at a faster rate than below. Rams may also extend from a vertical ice cliff, also known as an **ice front**, which forms the seaward face of a massive ice sheet or floating glacier; or from an **ice wall**, which is the ice cliff forming the seaward margin of a glacier which is aground. In addition to rams, large portions of an iceberg may extend well beyond the waterline at greater depths.

Strangely, icebergs may be helpful to the mariner in some ways. The melt water found on the surface of icebergs is a source of freshwater, and in the past some daring seamen have made their vessels fast to icebergs which, because they are affected more by currents than the wind, have proceeded to tow them out of the ice pack.

Icebergs can be used as a navigational aid in extreme latitudes where charted depths may be in doubt or non-existent. Since an iceberg (except a large tabular berg) must be at least as deep in the water as it is high to remain upright, a grounded berg can provide an estimate of the minimum water depth at its location. Water depth will be at least equal to the exposed height of the grounded iceberg. Grounded bergs remain stationary while current and wind move sea ice past them. Drifting ice may pile up against the upcurrent side of a grounded berg.

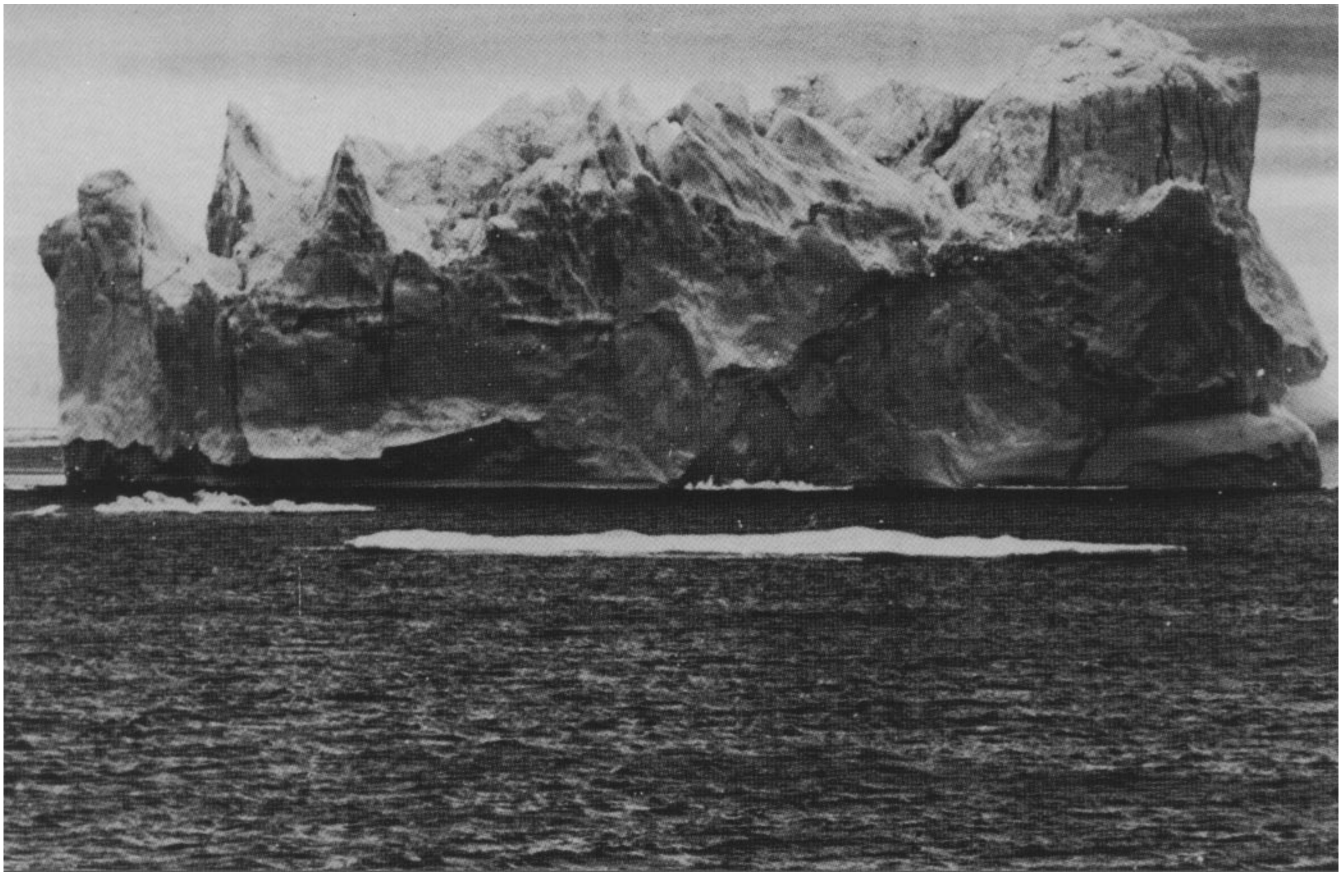


Figure 3402a. Pinnacled iceberg.

Figure 3402b. A tabular iceberg.

3403. Sea Ice

Sea ice forms by the freezing of seawater and accounts for 95 percent of all ice encountered. The first indication of the formation of new sea ice (up to 10 centimeters in thickness) is the development of small individual, needle-like crystals of ice, called **spicules**, which become suspended in the top few centimeters of seawater. These spicules, also known as **frazil ice**, give the sea surface an oily appearance. **Grease ice** is formed when the spicules coagulate to form a soupy layer on the surface, giving the sea a matte appearance. The next stage in sea ice formation occurs when **shuga**, an accumulation of spongy white ice lumps a few centimeters across, develops from grease ice. Upon further freezing, and depending upon wind exposure, seas, and salinity, shuga and grease ice develop into **nilas**, an elastic crust of high salinity, up to 10 centimeters in thickness, with a matte surface, or into **ice rind**, a brittle, shiny crust of low salinity with a thickness up to approximately 5 centimeters. A layer of 5 centimeters of freshwater ice is brittle but strong enough to support the weight of a heavy man. In contrast, the same thickness of newly formed sea ice will support not more than about 10 percent of this weight, although its strength varies with the temperatures at which it is formed; very cold ice supports a greater weight than warmer ice. As it ages, sea ice becomes harder and more brittle.

New ice may also develop from slush which is formed when snow falls into seawater which is near its freezing point, but colder than the melting point of snow. The snow does not melt, but floats on the surface, drifting with the wind into beds. If the temperature then drops below the freezing point of the seawater, the slush freezes quickly into a soft ice similar to shuga.

Sea ice is exposed to several forces, including currents, waves, tides, wind, and temperature variations. In its early stages, its plasticity permits it to conform readily to virtually any shape required by the forces acting upon it. As it becomes older, thicker, more brittle, and exposed to the influence of wind and wave action, new ice usually separates into circular pieces from 30 centimeters to 3 meters in diameter and up to approximately 10 centimeters in thickness with raised edges due to individual pieces striking against each other. These circular pieces of ice are called **pancake ice** (Figure 3403) and may break into smaller pieces with strong wave motion. Any single piece of relatively flat sea ice less than 20 meters across is called an **ice cake**. With continued low temperatures, individual ice cakes and pancake ice will, depending on wind or wave motion, either freeze together to form a continuous sheet or unite into pieces of ice 20 meters or more across. These larger pieces are then called **ice floes**, which may further freeze together to form an ice covered area greater than 10 kilometers across known as an **ice field**. In wind sheltered areas thickening ice usually forms a continuous sheet before it can develop into the characteristic ice cake form. When sea ice reaches a thickness of between 10 to 30 centimeters it is referred to as **gray** and **gray-white ice**, or collectively as **young ice**, and

Figure 3403. Pancake ice, with an iceberg in the background.

is the transition stage between nilas and first-year ice. First-year ice usually attains a thickness of between 30 centimeters and 2 meters in its first winter's growth.

Sea ice may grow to a thickness of 10 to 13 centimeters within 48 hours, after which it acts as an insulator between the ocean and the atmosphere progressively slowing its further growth. However, sea ice may grow to a thickness of between 2 to 3 meters in its first winter. Ice which has survived at least one summer's melt is classified as **old ice**. If it has survived only one summer's melt it may be referred to as **second-year ice**, but this term is seldom used today. Old ice which has attained a thickness of 3 meters or more and has survived at least two summers' melt is known as **multiyear ice** and is almost salt free. This term is increasingly used to refer to any ice more than one season old. Old ice can be recognized by a bluish tone to its surface color in contrast to the greenish tint of first-year ice, but it is often covered with snow. Another sign of old ice is a smoother, more rounded appearance due to melting/refreezing and weathering.

Greater thicknesses in both first and multiyear ice are attained through the deformation of the ice resulting from the movement and interaction of individual floes. Deformation processes occur after the development of new and young ice and are the direct consequence of the effects of winds, tides, and currents. These processes transform a relatively flat sheet of ice into pressure ice which has a rough surface. **Bending**, which is the first stage in the formation of pressure ice, is the upward or downward motion of thin and very plastic ice. Rarely, **tenting** occurs when bending produces an upward displacement of ice forming a flat sided arch with a cavity beneath. More frequently, however, **rafting** takes place as one piece of ice overrides another. When pieces of first-year ice are piled haphazardly over one another forming a wall or line of broken ice, referred to as a **ridge**, the process is known as **ridging**. Pressure ice with topography consisting of numerous mounds or hillocks is called

hummocked ice, each mound being called a **hummock**.

The motion of adjacent floes is seldom equal. The rougher the surface, the greater is the effect of wind, since each piece extending above the surface acts as a sail. Some ice floes are in rotary motion as they tend to trim themselves into the wind. Since ridges extend below as well as above the surface, the deeper ones are influenced more by deep water currents. When a strong wind blows in the same direction for a considerable period, each floe exerts pressure on the next one, and as the distance increases, the pressure becomes tremendous. Ridges on sea ice are generally about 1 meter high and 5 meters deep, but under considerable pressure may attain heights of 20 meters and depths of 50 meters in extreme cases.

The alternate melting and growth of sea ice, combined with the continual motion of various floes that results in separation as well as consolidation, causes widely varying conditions within the ice cover itself. The mean areal density, or concentration, of pack ice in any given area is expressed in tenths. Concentrations range from: open water (total concentration of all ice is less than one tenth), very open pack (1 to 3 tenths concentration), open pack (4 to 6 tenths concentration), close pack (7 to 8 tenths concentration), very close pack (9 to 10 to less than 10 to 10 concentration), to compact or consolidated pack (10 to 10 or complete coverage). The extent to which an ice cover of varying concentrations can be penetrated by a vessel varies from place to place and with changing weather conditions. With a concentration of 1 to 3 tenths in a given area, an unreinforced vessel can generally navigate safely, but the danger of receiving heavy damage is always present. When the concentration increases to between 3 and 5 tenths, the area becomes only occasionally accessible to an unreinforced vessel, depending upon the wind and current. With concentrations of 5 to 7 tenths, the area becomes accessible only to ice strengthened vessels, which on occasion will require icebreaker assistance. Navigation in areas with concentrations of 7 tenths or more should only be attempted by icebreakers.

Within the ice cover, openings may develop resulting from a number of deformation processes. Long, jagged **cracks** may appear first in the ice cover or through a single floe. When these cracks part and reach lengths of a few meters to many kilometers, they are referred to as **fractures**. If they widen further to permit passage of a ship, they are called **leads**. In winter, a thin coating of new ice may cover the water within a lead, but in summer the water usually remains ice-free until a shift in the movement forces the two sides together again. A lead ending in a pressure ridge or other impenetrable barrier is a **blind lead**.

A lead between pack ice and shore is a **shore lead**, and one between pack and fast ice is a **flaw lead**. Navigation in these two types of leads is dangerous, because if the pack ice closes with the fast ice, the ship can be caught between the two, and driven aground or caught in the shear zone between.

Before a lead refreezes, lateral motion generally occurs between the floes, so that they no longer fit and unless the pressure is extreme, numerous large patches of open water remain. These nonlinear shaped openings enclosed in ice are called **polynyas**. Polynyas may contain small fragments of floating ice and may be covered with miles of new and young ice. **Recurring polynyas** occur in areas where upwelling of relatively warmer water occurs periodically. These areas are often the site of historical native settlements, where the polynyas permit fishing and hunting at times before regular seasonal ice breakup. Thule, Greenland, is an example.

Sea ice which is formed *in situ* from seawater or by the freezing of pack ice of any age to the shore and which remains attached to the coast, to an ice wall, to an ice front, or between shoals is called **fast ice**. The width of this fast ice varies considerably and may extend for a few meters or several hundred kilometers. In bays and other sheltered areas, fast ice, often augmented by annual snow accumulations and the seaward extension of land ice, may attain a thickness of over 2 meters above the sea surface. When a floating sheet of ice grows to this or a greater thickness and extends over a great horizontal distance, it is called an **ice shelf**. Massive ice shelves, where the ice thickness reaches several hundred meters, are found in both the Arctic and Antarctic.

The majority of the icebergs found in the Antarctic do not originate from glaciers, as do those found in the Arctic, but are calved from the outer edges of broad expanses of shelf ice. Icebergs formed in this manner are called **tabular icebergs**, having a box like shape with horizontal dimensions measured in kilometers, and heights above the sea surface approaching 60 meters. See Figure 3402b. The largest Antarctic ice shelves are found in the Ross and Weddell Seas. The expression “tabular iceberg” is not applied to bergs which break off from Arctic ice shelves; similar formations there are called **ice islands**. These originate when shelf ice, such as that found on the northern coast of Greenland and in the bays of Ellesmere Island, breaks up. As a rule, Arctic ice islands are not as large as the tabular icebergs found in the Antarctic. They attain a thickness of up to 55 meters and on the average extend 5 to 7 meters above the sea surface. Both tabular icebergs and ice islands possess a gently rolling surface. Because of their deep draft, they are influenced much more by current than wind. Arctic ice islands have been used as floating scientific platforms from which polar research has been conducted.

3404. Thickness Of Sea Ice

Sea ice has been observed to grow to a thickness of almost 3 meters during its first year. However, the thickness of first-year ice that has not undergone deformation does not generally exceed 2 meters. In coastal areas where the melting rate is less than the freezing rate, the thickness may increase during succeeding winters, being augmented by compacted and frozen snow, until a maximum thickness of about 3.5 to 4.5 meters may eventually be reached. Old sea ice may also attain a thickness of over 4 meters in this manner, or when summer melt water from its surface or from snow cover runs off into the sea and refreezes under the ice where the seawater temperature is

below the freezing point of the fresher melt water.

The growth of sea ice is dependent upon a number of meteorological and oceanographic parameters. Such parameters include air temperature, initial ice thickness, snow depth, wind speed, seawater salinity and density, and the specific heats of sea ice and seawater. Investigations, however, have shown that the most influential parameters affecting sea ice growth are air temperature, wind speed, snow depth and initial ice thickness. Many complex equations have been formulated to predict ice growth using these four parameters. However, except for the first two, these parameters are not routinely observed for remote polar locations.

Field measurements suggest that reasonable growth estimates can be obtained from air temperature data alone. Various empirical formulae have been developed based on this premise. All appear to perform better under thin

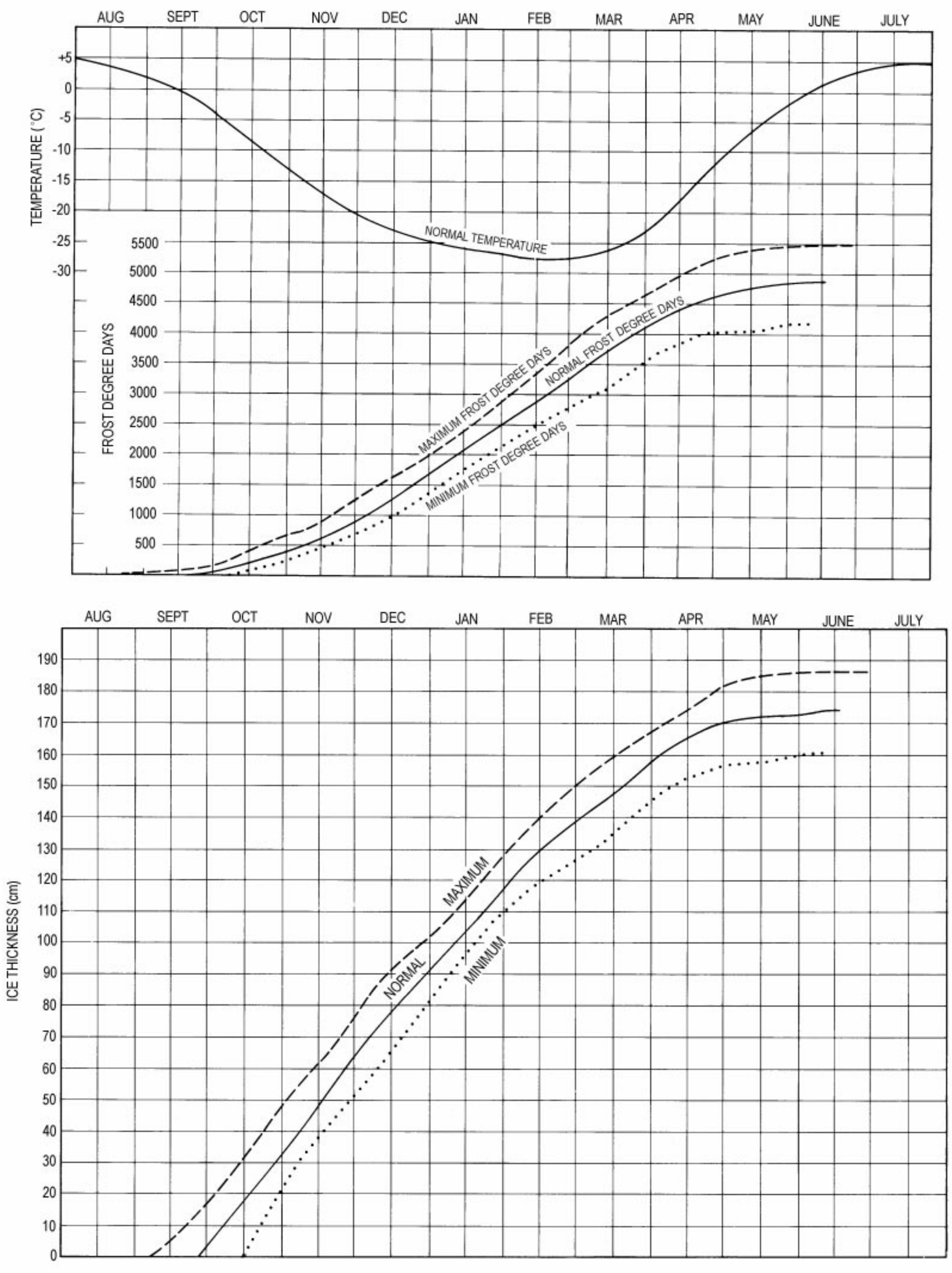


Figure 3404a. Relationship between accumulated frost degree days and theoretical ice thickness at Point Barrow, Alaska.

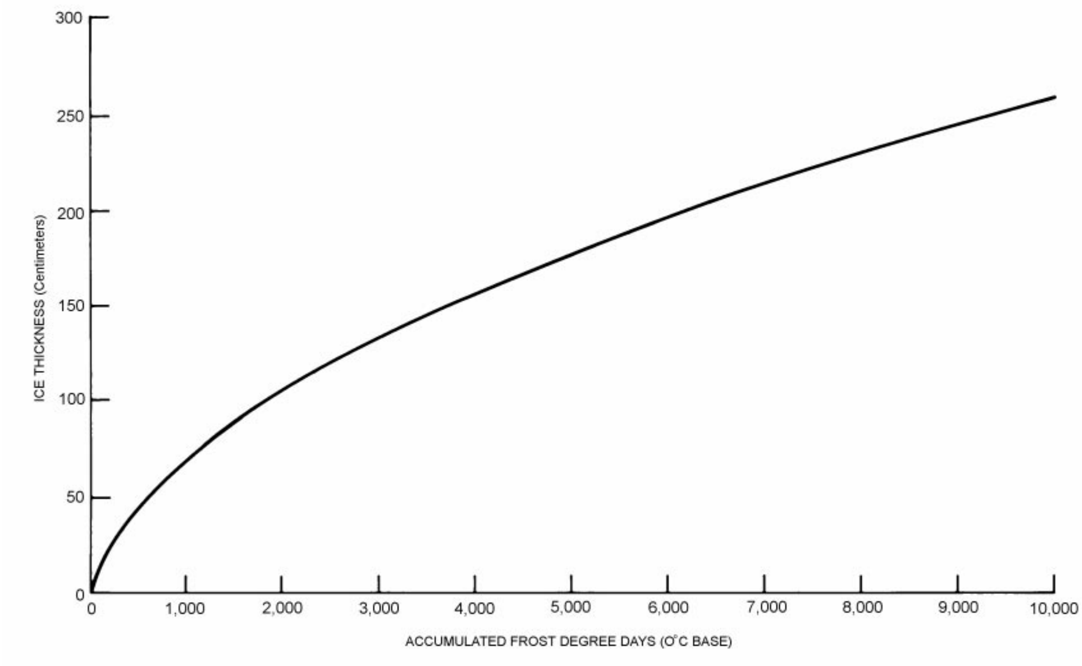


Figure 3404b. Relationship between accumlated frost degree days (°C) and ice thickness (cm).

ice conditions when the temperature gradient through the ice is linear, generally true for ice less than 100 centimeters thick. Differences in predicted thicknesses between models generally reflect differences in environmental parameters (snowfall, heat content of the underlying water column, etc.) at the measurement site. As a result, such equations must be considered partially site specific and their general use approached with caution. For example, applying an equation derived from central Arctic data to coastal conditions or to Antarctic conditions could lead to substantial errors. For this reason Zubov's formula is widely cited as it represents an average of many years of observations from the Russian Arctic:

$$h^2 + 50h = 8\phi$$

where h is the ice thickness in centimeters for a given day and ϕ is the cumulative number of frost degree days in degrees Celsius since the beginning of the freezing season.

A frost degree day is defined as a day with a mean temperature of 1° below an arbitrary base. The base most commonly used is the freezing point of freshwater (0°C). If, for example, the mean temperature on a given day is 5° below freezing, then five frost degree days are noted for that day. These frost degree days are then added to those noted the next day to obtain an accumulated value, which is then added to those noted the following day. This process is repeated daily throughout the ice growing season. Temperatures usually fluctuate above and below freezing for several days before remaining below freezing. Therefore, frost degree day accumulations are initiated on the first day of the period when temperatures remain below freezing. The relationship between frost degree day accumulations and theoretical ice growth curves at Point Barrow, Alaska is shown in Figure 3404a. Similar curves for other Arctic stations are contained in publications available from the U.S. Naval Oceanographic Office and the National Ice Center. Figure 3404b graphically depicts the relationship between accumulated frost degree days (°C) and ice thickness in centimeters.

During winter, the ice usually becomes covered with snow, which insulates the ice beneath and tends to slow down its rate of growth. This thickness of snow cover varies considerably from region to region as a result of differing climatic conditions. Its depth may also vary widely within very short distances in response to variable winds and ice topography. While this snow cover persists, about 80 to 85 percent of the incoming radiation is reflected back to space. Eventually, however, the snow begins to melt, as the air temperature rises above 0°C in early summer and the resulting freshwater forms puddles on the surface. These puddles absorb about 90 percent of the incoming radiation and rapidly enlarge as they melt the surrounding snow or ice. Eventually the puddles penetrate to the bottom surface of the floes and as **thawholes**. This slow process is characteristic of ice in the Arctic Ocean and seas where movement is restricted by the coastline or islands. Where ice is free to drift into warmer waters (e.g., the Antarctic, East Greenland, and the Labrador Sea), decay is accelerated in response to wave erosion as well as warmer air and sea temperatures.

3405. Salinity Of Sea Ice

Sea ice forms first as salt-free crystals near the surface

of the sea. As the process continues, these crystals are joined together and, as they do so, small quantities of brine are trapped within the ice. On the average, new ice 15 centimeters thick contains 5 to 10 parts of salt per thousand. With lower temperatures, freezing takes place faster. With faster freezing, a greater amount of salt is trapped in the ice.

Depending upon the temperature, the trapped brine may either freeze or remain liquid, but because its density is greater than that of the pure ice, it tends to settle down through the pure ice. As it does so, the ice gradually freshens, becoming clearer, stronger, and more brittle. At an age of 1 year, sea ice is sufficiently fresh that its melt water, if found in puddles of sufficient size, and not contaminated by spray from the sea, can be used to replenish the freshwater supply of a ship. However, ponds of sufficient size to water ships are seldom found except in ice of great age, and then much of the meltwater is from snow which has accumulated on the surface of the ice. When sea ice reaches an age of about 2 years, virtually all of the salt has been eliminated. Icebergs, having formed from precipitation, contain no salt, and uncontaminated melt water obtained from them is fresh.

The settling out of the brine gives sea ice a honeycomb structure which greatly hastens its disintegration when the temperature rises above freezing. In this state, when it is called **rotten ice**, much more surface is exposed to warm air and water, and the rate of melting is increased. In a day's time, a floe of apparently solid ice several inches thick may disappear completely.

3406. Density Of Ice

The density of freshwater ice at its freezing point is 0.917gm/cm^3. Newly formed sea ice, due to its salt content, is more dense, 0.925 gm/cm^3 being a representative value. The density decreases as the ice freshens. By the time it has shed most of its salt, sea ice is less dense than freshwater ice, because ice formed in the sea contains more air bubbles. Ice having no salt but containing air to the extent of 8 percent by volume (an approximately maximum value for sea ice) has a density of 0.845 gm/cm^3.

The density of land ice varies over even wider limits. That formed by freezing of freshwater has a density of 0.917gm/cm^3, as stated above. Much of the land ice, however, is formed by compacting of snow. This results in the entrapping of relatively large quantities of air. **Névé**, a snow which has become coarse grained and compact through temperature change, forming the transition stage to glacier ice, may have an air content of as much as 50 percent by volume. By the time the ice of a glacier reaches the sea, its density approaches that of freshwater ice. A sample taken from an iceberg on the Grand Banks had a density of 0.899gm/cm^3.

When ice floats, part of it is above water and part is below the surface. The percentage of the mass below the surface can be found by dividing the average density of the ice by the density of the water in which it floats. Thus, if an iceberg of density 0.920 floats in water of density 1.028 (corresponding to a salinity of 35 parts per thousand and a temperature of –1°C), 89.5 percent of its mass will be below the surface.

The height to draft ratio for a blocky or tabular iceberg probably varies fairly closely about 1:5. This average ratio was computed for icebergs south of Newfoundland by considering density values and a few actual measurements, and by seismic means at a number of locations along the edge of the Ross Ice Shelf near Little America Station. It was also substantiated by density measurements taken in a nearby hole drilled through the 256-meter thick ice shelf. The height to draft ratios of icebergs become significant when determining their drift.

3407. Drift Of Sea Ice

Although surface currents have some affect upon the drift of pack ice, the principal factor is wind. Due to Coriolis force, ice does not drift in the direction of the wind, but varies from approximately 18° to as much as 90° from this direction, depending upon the force of the surface wind and the ice thickness. In the Northern Hemisphere, this drift is to the right of the direction toward which the wind blows, and in the Southern Hemisphere it is toward the left. Although early investigators computed average angles of approximately 28° or 29° for the drift of close multiyear pack ice, large drift angles were usually observed with low, rather than high, wind speeds. The relationship between surface wind speed, ice thickness, and drift angle was derived theoretically for the drift of consolidated pack under equilibrium (a balance of forces acting on the ice) conditions, and shows that the drift angle increases with increasing ice thickness and decreasing surface wind speed. A slight increase also occurs with higher latitude.

Since the cross-isobar deflection of the surface wind over the oceans is approximately 20°, the deflection of the ice varies, from approximately along the isobars to as much as 70° to the right of the isobars, with low pressure on the left and high pressure on the right in the Northern Hemisphere. The positions of the low and high pressure areas are, of course, reversed in the Southern Hemisphere.

The rate of drift depends upon the roughness of the surface and the concentration of the ice. Percentages vary from approximately 0.25 percent to almost 8 percent of the surface wind speed as measured approximately 6 meters above the ice surface. Low concentrations of heavily ridged or hummocked floes drift faster than high concentrations of lightly ridged or hummocked floes with the same wind speed. Sea ice of 8 to 9 tenths concentrations and six tenths hummocking or close multiyear ice will drift at approximately 2 percent of the surface wind speed. Additionally, the response factors of 1 and 5 tenths ice concentrations, respectively, are approximately three times and twice the magnitude of the response factor for 9 tenths ice concentrations with the same extent of surface roughness. Isolated ice floes have been observed to drift as fast as 10 percent to 12 percent of strong surface winds.

The rates at which sea ice drifts have been quantified

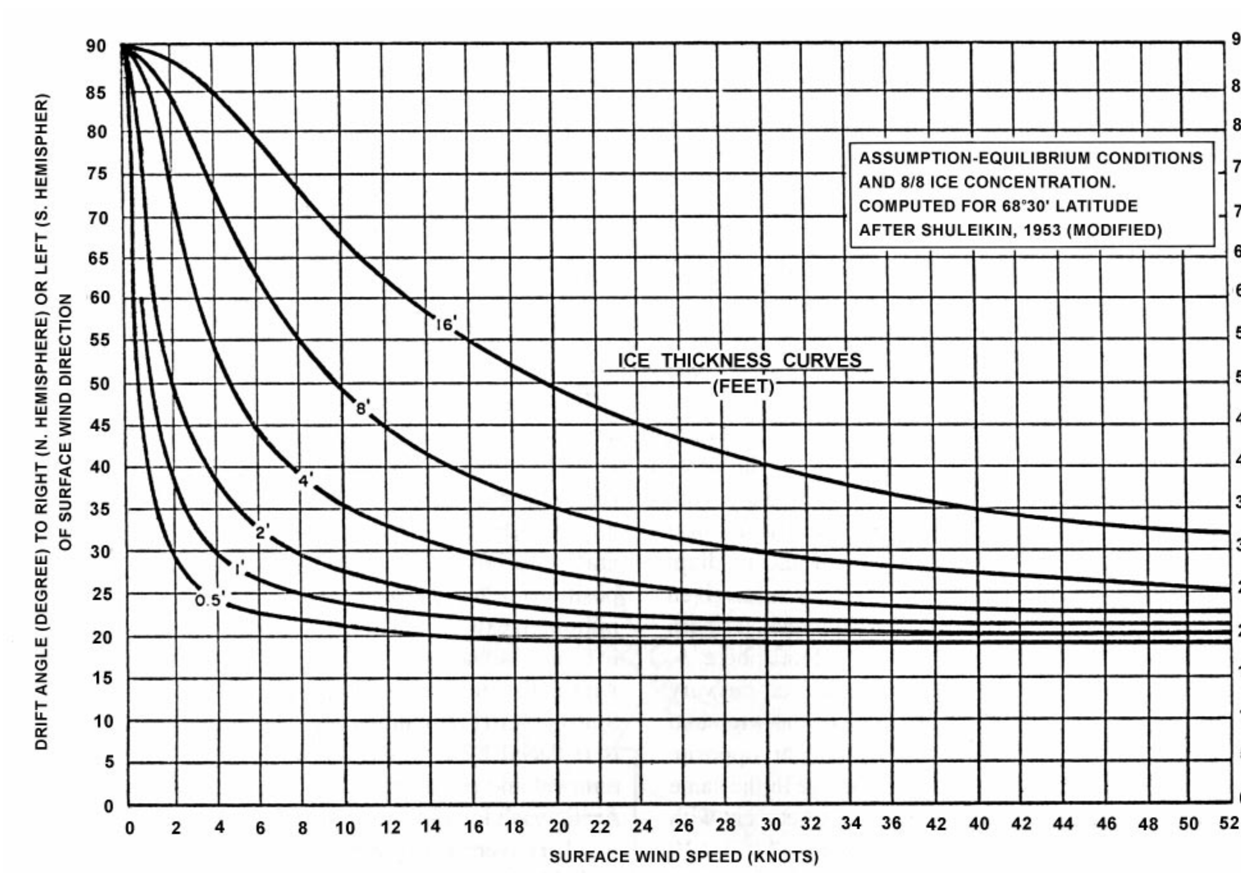


Figure 3407. Ice drift direction for varying wind speed and ice thickness.

through empirical observation. The drift angle, however, has been determined theoretically for 10 tenths ice concentration. This relationship presently is extended to the drift of all ice concentrations, due to the lack of basic knowledge of the dynamic forces that act upon, and result in redistribution of sea ice, in the polar regions.

3408. Iceberg Drift

Icebergs extend a considerable distance below the surface and have relatively small "sail areas" compared to their subsurface mass. Therefore, the near-surface current is thought to be primarily responsible for drift; however, observations have shown that wind can be the dominant force that governs iceberg drift at a particular location or time. Also, the current and wind may contribute nearly equally to the resultant drift.

Two other major forces which act on a drifting iceberg are the Coriolis force and, to a lesser extent, the pressure gradient force which is caused by gravity owing to a tilt of the sea surface, and is important only for iceberg drift in a major current. Near-surface currents are generated by a variety of factors such as horizontal pressure gradients owing to density variations in the water, rotation of the earth, gravitational attraction of the moon, and slope of the sea surface. Wind not only acts directly on an iceberg, but also indirectly by generating waves and a surface current in about the same direction as the wind. Because of inertia, an iceberg may continue to move from the influence of wind for some time after the wind stops or changes direction.

The relative influence of currents and winds on the drift of an iceberg varies according to the direction and magnitude of the forces acting on its sail area and subsurface cross-sectional area. The resultant force therefore involves the proportions of the iceberg above and below the sea surface in relation to the velocity and depth of the current, and the velocity and duration of the wind. Studies tend to show that, generally, where strong currents prevail, the current is dominant. In regions of weak currents, however, winds that blow for a number of hours in a steady direction materially affect the drift of icebergs. Generally, it can be stated that currents tend to have a greater effect on deep-draft icebergs, while winds tend to have a greater effect on shallow-draft icebergs.

As icebergs waste through melting, erosion, and calving, observations indicate the height to draft ratio may approach 1:1 during their last stage of decay, when they are referred to as valley, winged, horned, or spired icebergs.

The height to draft ratios found for icebergs in their various stages are presented in Table 3408a. Since wind tends to have a greater effect on shallow than on deep-draft icebergs, the wind can be expected to exert increasing influence on iceberg drift as wastage increases.

Simple equations which precisely define iceberg drift cannot be formulated at present because of the uncertainty in the water and air drag coefficients associated with iceberg motion. Values for these parameters not only vary from iceberg to iceberg, but they probably change for the same iceberg over its period of wastage.

Present investigations utilize an analytical approach, facilitated by computer calculations, in which the air and water drag coefficients are varied within reasonable limits. Combinations of these drag values are then used in several increasingly complex water models that try to duplicate observed iceberg trajectories. The results indicate that with a wind-generated current, Coriolis force, and a uniform wind, but without a gradient current, small and medium icebergs will drift with the percentages of the wind as given in Table 3408b. The drift will be to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

When gradient currents are introduced, trajectories vary considerably depending on the magnitude of the wind and current, and whether they are in the same or opposite direction. When a 1-knot current and wind are in the same direction, drift is to the right of both wind and current with drift angles increasing linearly from approximately 5° at 10 knots to 22° at 60 knots. When the wind and a 1-knot current are in opposite directions, drift is to the left of the current, with the angle increasing from approximately 3° at 10 knots, to 20° at 30 knots, and to 73° at 60 knots. As a limiting case for increasing wind speeds, drift may be approximately normal (to the right) to the wind direction. This indicates that the wind generated current is clearly dominating the drift. In general, the various models used demonstrated that a combination of the wind and current was responsible for the drift of icebergs.

3409. Extent Of Ice In The Sea

When an area of sea ice, no matter what form it takes or how it is disposed, is described, it is referred to as **pack ice**. In both polar regions the pack ice is a very dynamic feature, with wide deviations in its extent dependent upon changing oceanographic and meteorological phenomena. In winter the Arctic pack extends over the entire Arctic Ocean, and for a varying distance outward from it; the limits recede considerably during the warmer summer months. The average positions of the seasonal absolute and mean maximum and minimum extents of sea ice in the Arctic region are plotted in Figure 3409a. Each year a large portion of the ice from the Arctic Ocean moves outward between Greenland and Spitsbergen (Fram Strait) into the North Atlantic Ocean and is replaced by new ice. Because of this constant annual removal and replacement of sea ice, relatively little of the Arctic pack ice is more than 10 years old.

Ice covers a large portion of the Antarctic waters and is probably the greatest single factor contributing to the isolation of the Antarctic Continent. During the austral winter

Iceberg type	*Height to draft ratio*
Blocky or tabular	1:5
Rounded or domed	1:4
Picturesque or Greenland (sloping)	1:3
Pinnacled or ridged	1:2
Horned, winged, valley, or spired (weathered)	1:1

Table 3408a. Height to draft ratios for various types of icebergs.

Wind Speed (knots)	*Ice Speed/Wind Speed (percent)*		*Drift Angle (degrees)*	
	Small Berg	*Med. Berg*	*Small Berg*	*Med. Berg*
10	3.6	2.2	12	69
20	3.8	3.1	14	55
30	4.1	3.4	17	36
40	4.4	3.5	19	33
50	4.5	3.6	23	32
60	4.9	3.7	24	31

Table 3408b. Drift of iceberg as percentage of wind speed.

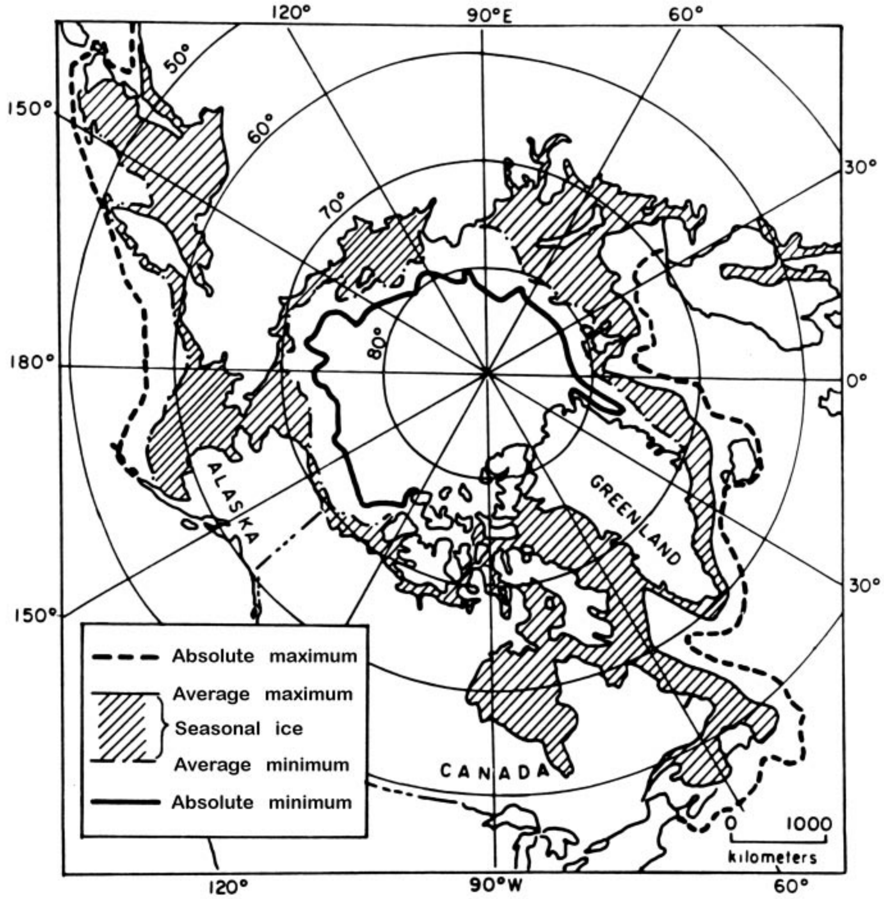


Figure 3409a. Average maximum and minimum extent of Arctic sea ice.

(June through September), ice completely surrounds the continent, forming an almost impassable barrier that extends northward on the average to about 54°S in theAtlantic and to about 62°S in the Pacific. Disintegration of the pack ice during the austral summer months of December through March allows the limits of the ice edge to recede considerably, opening some coastal areas of the Antarctic to navigation. The seasonal absolute and mean maximum and minimum positions of the Antarctic ice limit are shown in Figure 3409b.

Historical information on sea conditions for specific localities and time periods can be found in publications of the Naval Ice Center/National Ice Center (formerly Naval Polar Oceanography Center/U.S. Navy/NOAA Joint Ice Center) and the National Imagery and Mapping Agency (NIMA). National Ice Center (NIC) publications include sea ice annual atlases (1972 to present for Eastern Arctic, Western Arctic and Antarctica), sea ice climatologies, and forecasting guides. NIC sea ice annual atlases include years 1972 to the present for all Arctic and Antarctic seas. NIC ice climatologies describe multiyear statistics for ice extent and coverage. NIC forecasting guides cover procedures for the production of short-term (daily, weekly), monthly, and seasonal predictions. DMAHTC publications include sailing directions which describe localized ice conditions and the effect of ice on Arctic navigation.

3410. Icebergs In The North Atlantic

Sea level glaciers exist on a number of landmasses bordering the northern seas, including Alaska, Greenland, Svalbard (Spitsbergen), Zemlya Frantsa-Iosifa (Franz Josef Land), Novaya Zemlya, and Severnaya Zemlya (Nicholas II Land). Except in Greenland and Franz Josef Land, the rate of calving is relatively slow, and the few icebergs produced melt near their points of formation. Many of those produced along the western coast of Greenland, however, are eventually carried into the shipping lanes of the North Atlantic, where they constitute a major menace to ships. Those calved from Franz Josef Land glaciers drift southwest in the Barents Sea to the vicinity of Bear Island.

Generally the majority of icebergs produced along the

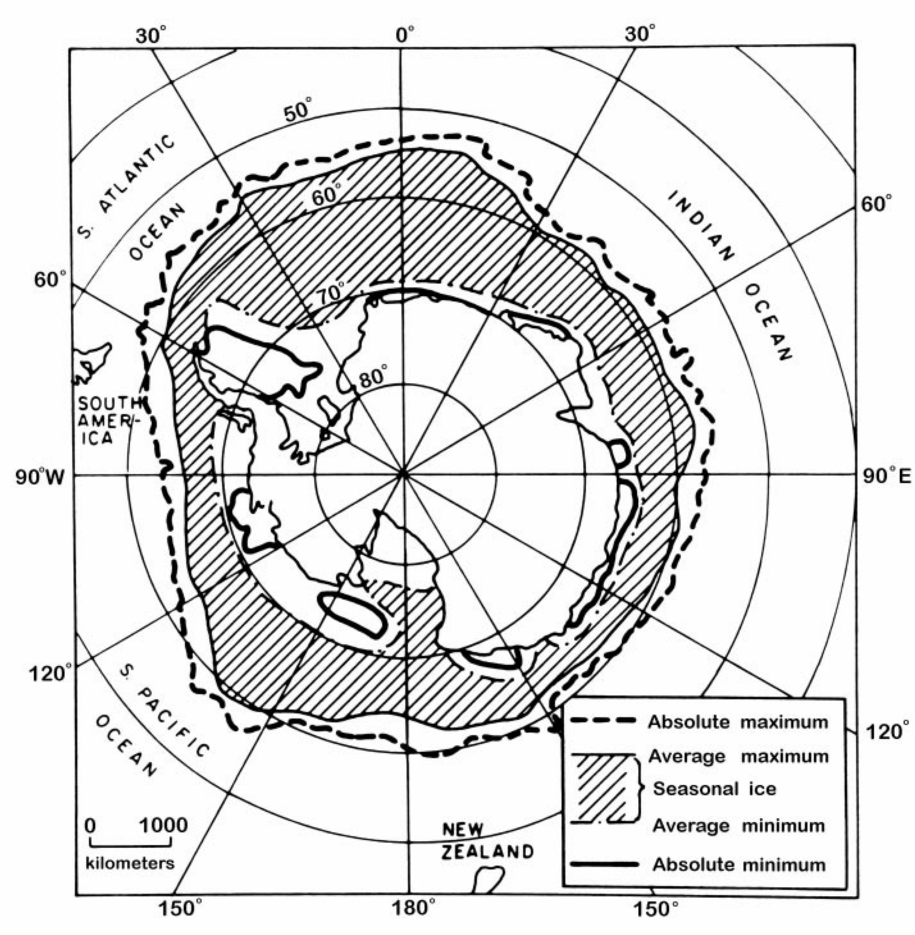


Figure 3409b. Average maximum and minimum extent of Antarctic sea ice.

east coast of Greenland remain near their source. However, a small number of bergy bits, growlers, and small icebergs are transported south from this region by the East Greenland Current around Kap Farvel at the southern tip of Greenland and then northward by the West Greenland Current into Davis Strait to the vicinity of 67°N. Relatively few of these icebergs menace shipping, but some are carried to the south and southeast of Kap Farvel by a counterclockwise current gyre centered near 57°N and 43°W.

The main source of the icebergs encountered in the North Atlantic is the west coast of Greenland between 67°N and 76°N, where approximately 10,000–15,000 icebergs are calved each year. In this area there are about 100 low-lying coastal glaciers, 20 of them being the principal producers of icebergs. Of these 20 major glaciers, 2 located in Disko Bugt between 69°N and 70°N are estimated to contribute 28 percent of all icebergs appearing in Baffin Bay and the Labrador Sea. The West Greenland Current carries icebergs from this area northward and then westward until they encounter the south flowing Labrador Current. West Greenland icebergs generally spend their first winter locked in the Baffin Bay pack ice; however, a large number can also be found within the sea ice extending along the entire Labrador coast by late winter. During the next spring and summer, when they are freed by the break up of the pack ice, they are transported farther southward by the Labrador Current. The general drift patterns of icebergs that are prevalent in the eastern portion of the North American Arctic are shown in Figure 3410a. Observations over a 79-year period show that an average of 427 icebergs per year reach latitudes south of 48°N, with approximately 10 percent of this total carried south of the Grand Banks (43°N) before they melt. Icebergs may be encountered during any part of the year, but in the Grand Banks area they are most numerous during spring. The maximum monthly average of iceberg sightings below 48°N occurs during April, May and June, with May having the highest average of 129.

The variation from average conditions is considerable. More than 2,202 icebergs have been sighted south of latitude 48°N in a single year (1984), while in 1966 not a single iceberg was encountered in this area. In the years of 1940 and 1958, only one iceberg was observed south of 48°N. The length of the iceberg "season" as defined by the International Ice Patrol also varies considerably, from 97

days in 1965 to 203 days in 1992, with an average length of 132 days. Although this variation has not been fully explained, it is apparently related to wind conditions, the distribution of pack ice in Davis Strait, and to the amount of pack ice off Labrador. It has been suggested that the distribution of the Davis Strait-Labrador Sea pack ice influences the melt rate of the icebergs as they drift south. Sea ice will decrease iceberg erosion by damping waves and holding surface water temperatures below 0°C, so as the areal extent of the sea ice increases the icebergs will tend to survive longer.

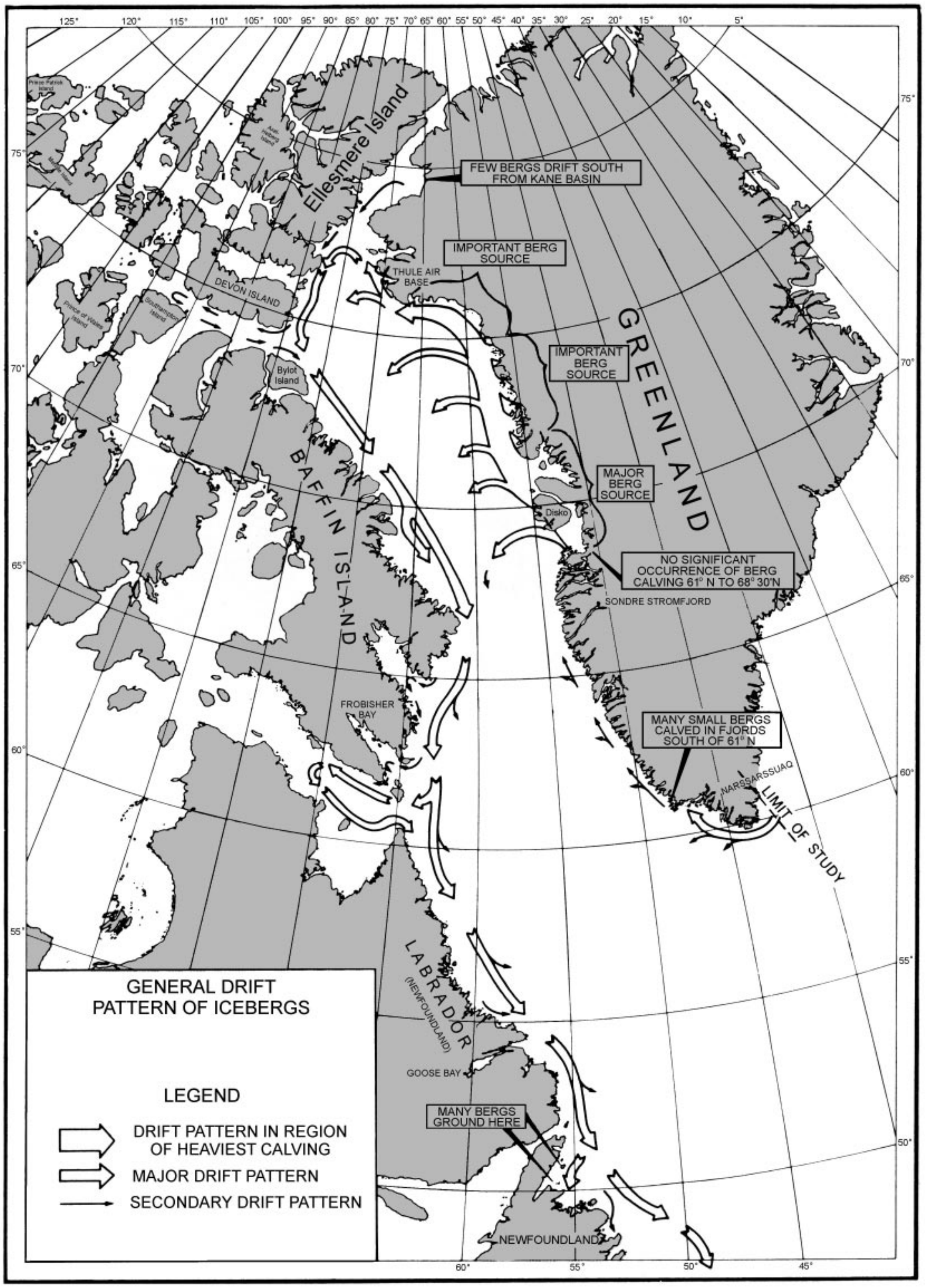


Figure 3410a. General drift pattern of icebergs.

Stronger than average northerly or northeasterly winds during late winter and spring will enhance sea ice drift to the south, which also may lengthen iceberg lifetimes. There are also large interannual variations in the number of icebergs calved from Greenland's glaciers, so the problem of forecasting the length and severity of an iceberg season is exceedingly complex.

Average iceberg and pack ice limits in this area during May are shown in Figure 3410b. Icebergs have been observed in the vicinity of Bermuda, the Azores, and within 400 to 500 kilometers of Great Britain.

Pack ice may also be found in the North Atlantic, some having been brought south by the Labrador Current and some coming through Cabot Strait after having formed in the Gulf of St. Lawrence.

3411. The International Ice Patrol

The International Ice Patrol was established in 1914 by the *International Convention for the Safety of Life at Sea* (SOLAS), held in 1913 as a result of the sinking of the RMS *Titanic* in 1912. The *Titanic* struck an iceberg on its maiden voyage and sank with the loss of 1,513 lives. In accordance with the agreement reached at the SOLAS conventions of 1960 and 1974, the International Ice Patrol is conducted by the U.S. Coast Guard, which is responsible for the observation and dissemination of information concerning ice conditions in the North Atlantic. Information on ice conditions for the Gulf of St. Lawrence and the coastal waters of Newfoundland and Labrador, including the Strait of Belle Isle, is provided by ECAREG Canada (Eastern Canada Traffic System), through any Coast Guard Radio Station, from the month of December through late June. Sea ice data for these areas can also be obtained from the Ice Operations Officer, located at Dartmouth, Nova Scotia, via Sydney, Halifax, or St. John's marine radio.

During the war years of 1916-18 and 1941-45, the Ice Patrol was suspended. Aircraft were added to the patrol force

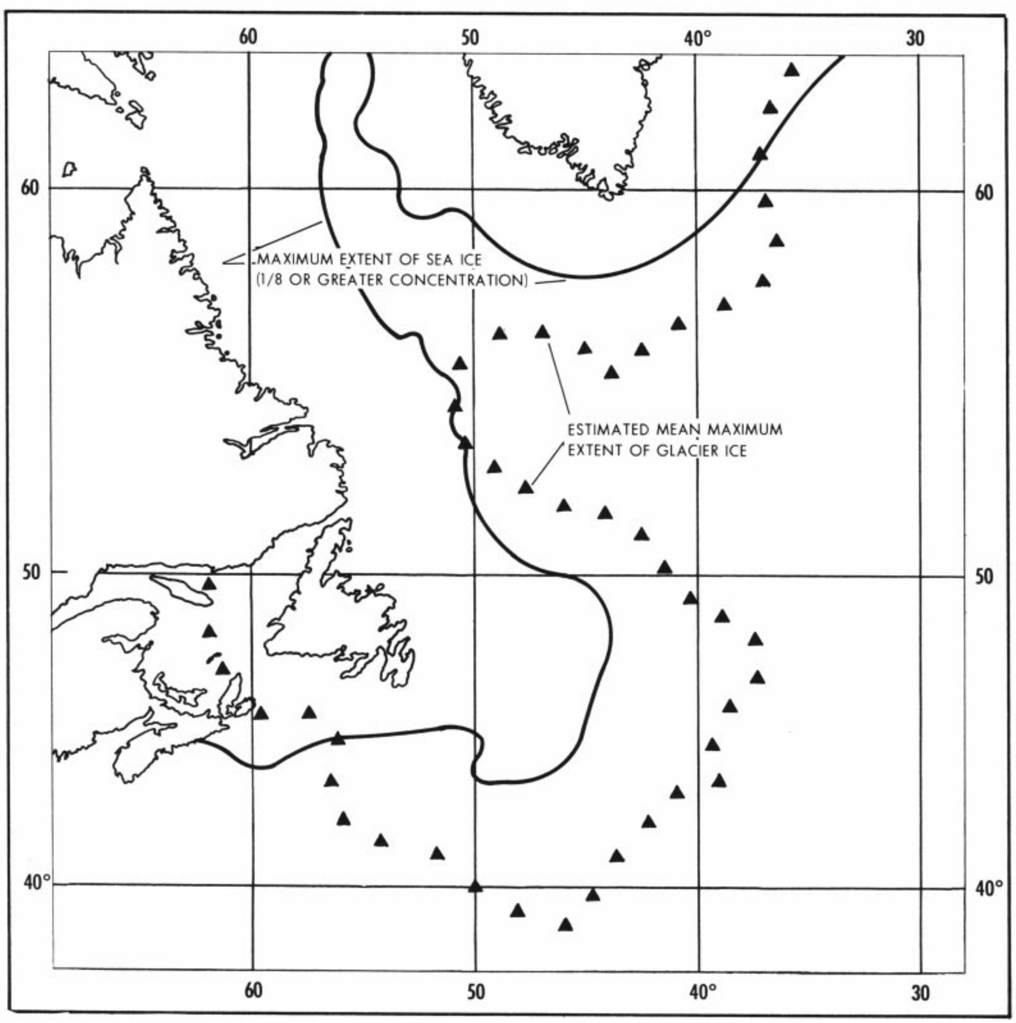


Figure 3410b. Average iceberg and pack ice limits during the month of May.

following World War II, and today perform the majority of the reconnaissance work. During each ice season, aerial reconnaissance surveys are made in the vicinity of the Grand Banks off Newfoundland to determine the southeastern, southern, and southwestern limit of the seaward extent of icebergs. The U.S. Coast Guard aircraft use Side-Looking Airborne Radar (SLAR) as well as Forward-Looking Airborne Radar (FLAR) to help detect and identify icebergs in this notoriously fog-ridden area. Reports of ice sightings are also requested and collected from ships transiting the Grand Banks area. When reporting ice, vessels are requested to detail the concentration and stage of development of sea ice, number of icebergs, the bearing of the principal sea ice edge, and the present ice situation and trend over the preceding three hours. These five parameters are part of the ICE group of the ship synoptic code which is addressed in more detail in Section 3416 on ice observation. In addition to ice reports, masters who do not issue routine weather reports are urged to make sea surface temperature and weather reports to the Ice Patrol every six hours when within latitudes 40° to 52°N and longitudes 38° to 58°W (the Ice Patrol Operations Area). Ice reports may be sent at no charge using INMARSAT Code 42.

The Ice Patrol activities are directed from an Operations Center at Avery Point, Groton, Connecticut. The Ice Patrol gathers all sightings and puts them into a computer model which analyzes and predicts iceberg drift and deterioration. Due to the large size of the Ice Patrol's operations area, icebergs are infrequently resighted. The model predictions are crucial to setting the limits of all known ice. The fundamental model force balance is between iceberg acceleration and accelerations due to air and water drag, the Coriolis force, and a sea surface slope term. The model is primarily driven by a water current that combines a depth- and time-independent geostrophic (mean) current with a depth- and time-dependent current driven by the wind (Ekman flow).

Environmental parameters for the model, including sea surface temperature, wave height and period, and wind, are obtained from the U.S. Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California every 12 hours. The International Ice Patrol also deploys from 12–15 World Ocean Circulation Experiment (WOCE) drifting buoys per year, and uses the buoy drifts to alter the climatological mean (geostrophic) currents used by the model in the immediate area of the buoys. The buoy drift data have been archived at the National Oceanographic Data Center (NODC) and are available for use by researchers outside the Coast Guard. Sea surface temperature, wave height and wave period are the main forces determining the rate of iceberg deterioration. Ship observations of these variables are extremely important in making model inputs more accurately reflect actual situations.

The results from the iceberg drift and deterioration model are used to compile bulletins that are issued twice daily during the ice season by radio communications from Boston, Massachusetts; St. John's, Newfoundland; and other radio stations. Bulletins are also available over INMARSAT. When icebergs are sighted outside the known limits of ice, special safety broadcasts are issued in between the regularly scheduled bulletins. Iceberg positions in the ice bulletins are updated for drift and deterioration at 12-hour intervals. A radio-facsimile chart is also broadcast twice a day throughout the ice season. A summary of broadcast times and frequencies is found in *Pub. 117, Radio Navigational Aids*.

The Ice Patrol, in addition to patrolling possible iceberg areas, conducts oceanographic surveys, maintains up-to-date records of the currents in its area of operation to aid in predicting the drift of icebergs, and studies iceberg conditions in general.

3412. Ice Detection

Safe navigation in the polar seas depends on a number of factors, not the least of which is accurate knowledge of the location and amount of sea ice that lies between the mariner and his destination. Sophisticated electronic equipment, such as radar, sonar, and the visible, infrared, and microwave radiation sensors on board satellites, have added to our ability to detect and thus avoid ice.

As a ship proceeds into higher latitudes, the first ice encountered is likely to be in the form of icebergs, because such large pieces require a longer time to disintegrate. Icebergs can easily be avoided if detected soon enough. The distance at which an iceberg can be seen visually depends upon meteorological visibility, height of the iceberg, source and condition of lighting, and the observer. On a clear day with excellent visibility, a large iceberg might be sighted at a distance of 20 miles. With a low-lying haze around the horizon, this distance will be reduced. In light fog or drizzle this distance is further reduced, down to near zero in heavy fog.

In a dense fog an iceberg may not be perceptible until it is close aboard where it will appear in the form of a luminous, white object if the sun is shining; or as a dark, somber mass with a narrow streak of blackness at the waterline if the sun is not shining. If the layer of fog is not too thick, an iceberg may be sighted from aloft sooner than from a point lower on the vessel, but this does not justify omitting a bow lookout. The diffusion of light in a fog will produce a **blink**, or area of whiteness, above and at the sides of an iceberg which will appear to increase the apparent size of its mass.

On dark, clear nights icebergs may be seen at a distance of from 1 to 3 miles, appearing either as white or black objects with occasional light spots where waves break against it. Under such conditions of visibility growlers are a greater menace to vessels; the vessel's speed should be reduced and a sharp lookout maintained.

The moon may either help or hinder, depending upon its phase and position relative to ship and iceberg. A full moon

in the direction of the iceberg interferes with its detection, while moonlight from behind the observer may produce a blink which renders the iceberg visible for a greater distance, as much as 3 or more miles. A clouded sky at night, through which the moonlight is intermittent, also renders ice detection difficult. A night sky with heavy passing clouds may also dim or obscure any object which has been sighted, and fleecy cumulus and cumulonimbus clouds often may give the appearance of blink from icebergs.

If an iceberg is in the process of disintegration, its presence may be detected by a cracking sound as a piece breaks off, or by a thunderous roar as a large piece falls into the water. These sounds are unlikely to be heard due to shipboard noise. The appearance of small pieces of ice in the water often indicates the presence of an iceberg nearby. In calm weather these pieces may form a curved line with the parent iceberg on the concave side. Some of the pieces broken from an iceberg are themselves large enough to be a menace to ships.

As the ship moves closer towards areas known to contain sea ice, one of the most reliable signs that pack ice is being approached is the absence of swell or wave motion in a fresh breeze or a sudden flattening of the sea, especially from leeward. The observation of icebergs is not a good indication that pack ice will be encountered soon, since icebergs may be found at great distances from pack ice. If the sea ice is approached from windward, it is usually compacted and the edge will be sharply defined. However, if it is approached from leeward, the ice is likely to be loose and somewhat scattered, often in long narrow arms.

Another reliable sign of the approach of pack ice not yet in sight is the appearance of a pattern, or **sky map**, on the horizon or on the underside of distant, extensive cloud areas, created by the varying amounts of light reflected from different materials on the sea or earth's surface. A bright white glare, or **snow blink**, will be observed above a snow covered surface. When the reflection on the underside of clouds is caused by an accumulation of distant ice, the glare is a little less bright and is referred to as an **ice blink**. A relatively dark pattern is reflected on the underside of clouds when it is over land that is not snow covered. This is known as a **land sky**. The darkest pattern will occur when the clouds are above an open water area, and is called a **water sky**. A mariner experienced in recognizing these sky maps will find them useful in avoiding ice or searching out openings which may permit his vessel to make progress through an ice field.

Another indication of the presence of sea ice is the formation of thick bands of fog over the ice edge, as moisture condenses from warm air when passing over the colder ice. An abrupt change in air or sea temperature or seawater salinity is *not* a reliable sign of the approach of icebergs or pack ice.

The presence of certain species of animals and birds can also indicate that pack ice is in close proximity. The sighting of walruses, seals, or polar bears in the Arctic should warn the mariner that pack ice is close at hand. In the Antarctic, the usual precursors of sea ice are penguins, terns, fulmars, petrels, and skuas.

When visibility becomes limited, radar can prove to be an invaluable tool for the polar mariner. Although many icebergs will be observed visually on clear days before there is a return on the radarscope, radar under bad weather conditions will detect the average iceberg at a range of about 8 to 10 miles. The intensity of the return is a function of the nature of the iceberg's exposed surface (slope, surface roughness); however, it is unusual to find an iceberg which will not produce a detectable echo.

Large, vertical-sided tabular icebergs of the Antarctic and Arctic ice islands are usually detected by radar at ranges of 15 to 30 miles; a range of 37 miles has been reported.

Whereas a large iceberg is almost always detected by radar in time to be avoided, a growler large enough to be a serious menace to a vessel may be lost in the sea return and escape detection. If an iceberg or growler is detected by radar, tracking is sometimes necessary to distinguish it from a rock, islet, or another ship.

Radar can be of great assistance to an experienced radar observer. Smooth sea ice, like smooth water, returns little or no echo, but small floes of rough, hummocky sea ice capable of inflicting damage to a ship can be detected in a smooth sea at a range of about 2 to 4 miles. The return may be similar to sea return, but the same echoes appear at each sweep. A lead in smooth ice is clearly visible on a radarscope, even though a thin coating of new ice may have formed in the opening. A light covering of snow obliterating many of the features to the eye has little effect upon a radar return. The ranges at which ice can be detected by radar are somewhat dependent upon refraction, which is sometimes quite abnormal in polar regions. Experience in interpretation is gained through comparing various radar returns with actual observations.

Echoes from the ship's whistle or horn may sometimes indicate the presence of icebergs and can give an indication of direction. If the time interval between the sound and its echo is measured, the distance in meters can be determined by multiplying the number of seconds by 168. However, echoes are very unreliable reliable because only ice with a large vertical area facing the ship returns enough echo to be heard. Once an echo is heard, a distinct pattern of horn blasts (not a Navigational Rules signal) should be made to confirm that the echo is not another vessel.

At relatively short ranges, sonar is sometimes helpful in locating ice. The initial detection of icebergs may be made at a distance of about 3 miles or more, but usually considerably less. Growlers may be detected at a distance of $^1/_2$ to 2 miles, and even smaller pieces may be detected in time to avoid them.

Ice in the polar regions is best detected and observed from the air, either from aircraft or by satellite. Fixed-winged aircraft have been utilized extensively for obtaining detailed aerial ice reconnaissance information since the early 1930's, and will no doubt continue to provide this invaluable service for many years to come. Some ships, particularly icebreakers, proceeding into high latitudes car-

ry helicopters, which are invaluable in locating leads and determining the relative navigability of different portions of the ice pack. Ice reports from personnel at Arctic and Antarctic coastal shore stations can also prove valuable to the polar mariner.

The enormous ice reconnaissance capabilities of meteorological satellites were confirmed within hours of the launch by the National Aeronautics and Space Administration (NASA) of the first experimental meteorological satellite, TIROS I, on April 1, 1960. With the advent of the polar-orbiting meteorological satellites during the mid and late 1960's, the U.S. Navy initiated an operational satellite ice reconnaissance program which could observe ice and its movement in any region of the globe on a daily basis, depending upon solar illumination. Since then, improvements in satellite sensor technology have provided a capability to make detailed global observations of ice properties under all weather and lighting conditions. The current suite of airborne and satellite sensors employed by the National Ice Center include: aerial reconnaissance including visual and Side-Looking Airborne Radar (SCAR), TIROS AVHRR visual and infrared, Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) visual and infrared, all-weather passive microwave from the DMSP Special Sensor Microwave Imager (SSM/I) and the ERS-1 Synthetic Aperture Radar (SAR). Examples of satellite imagery of ice covered waters are shown in Figure 3412a and Figure 3412b.

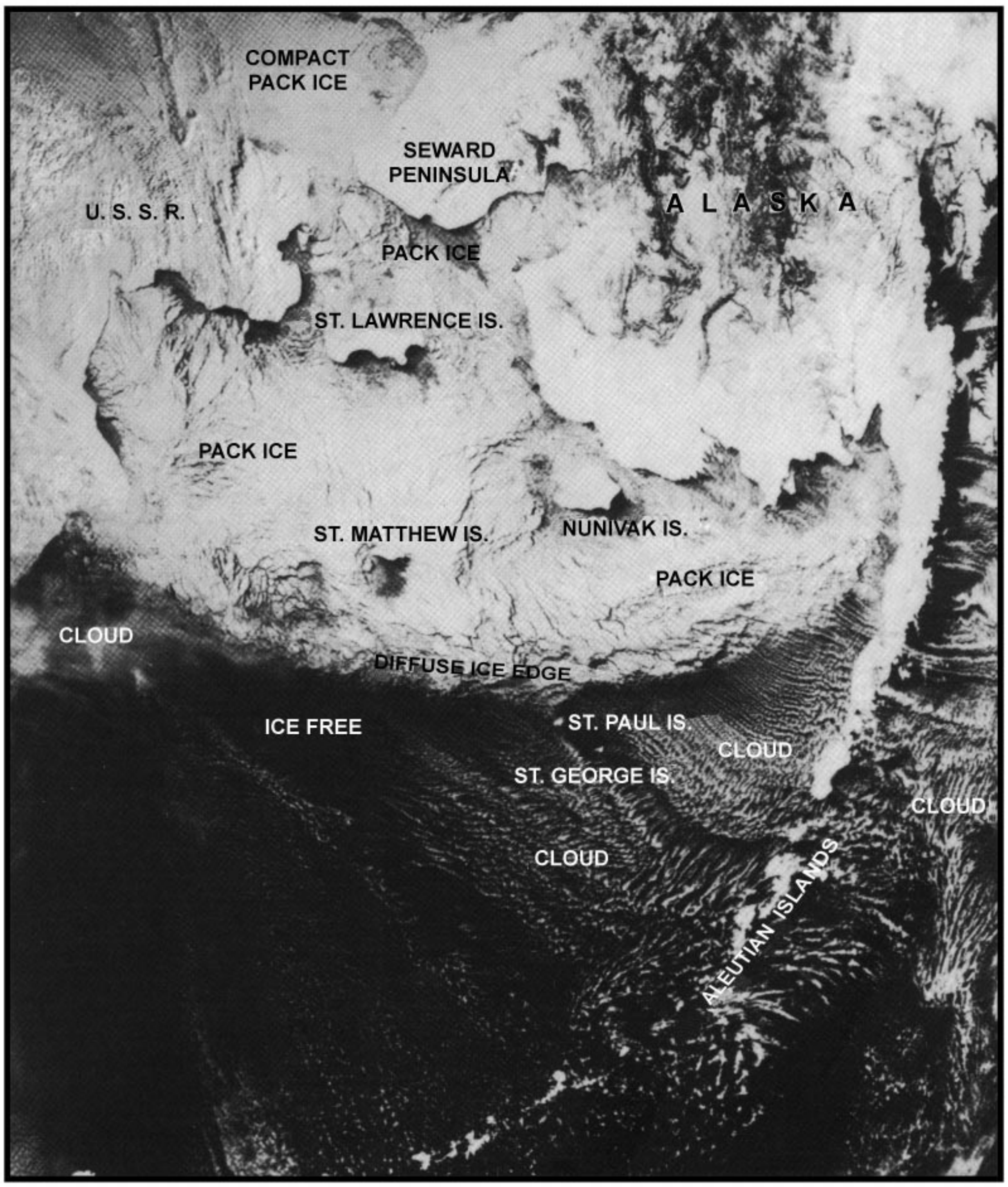


Figure 3412a. Example of satellite imagery with a resolution of 0.9 kilometer.

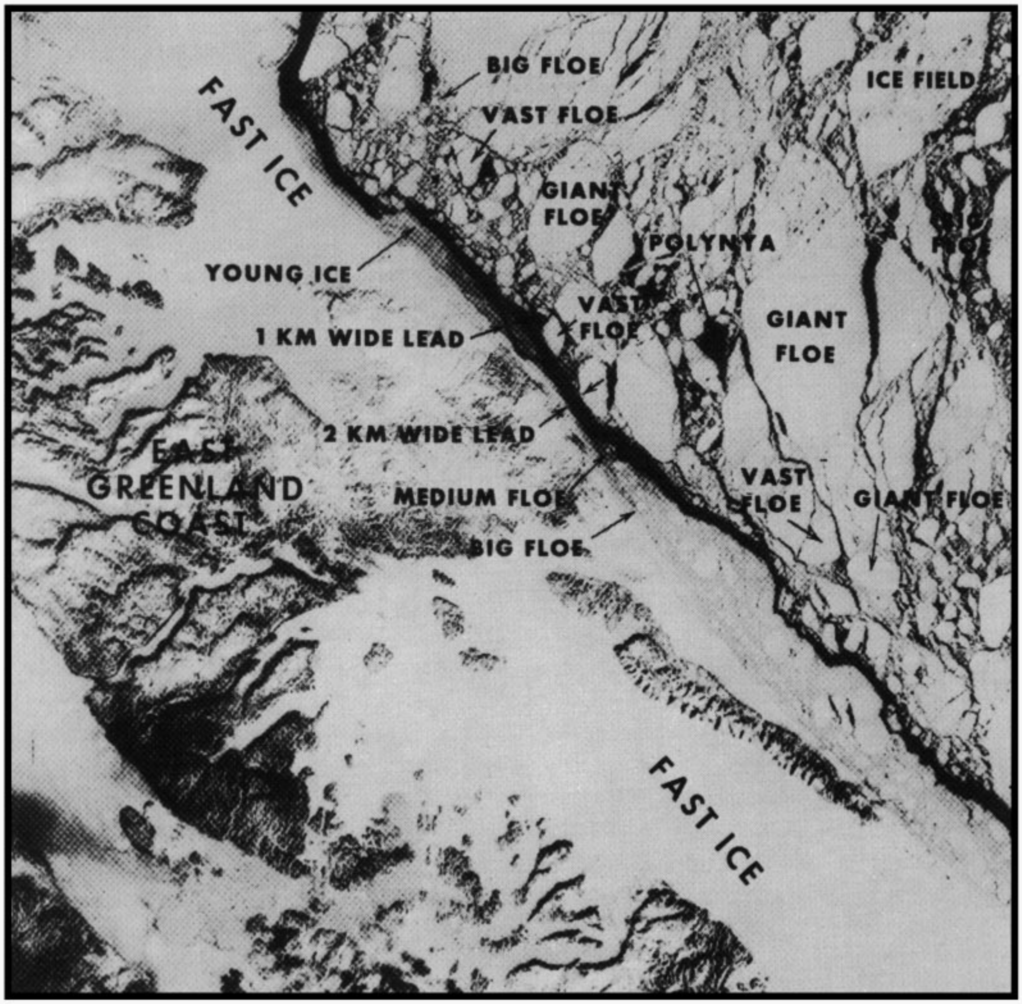


Figure 3412b. Example of satellite imagery with a resolution of 80 meters.

3413. Operations In Ice

Operations in ice-prone regions necessarily require considerable advanced planning and many more precautionary measures than those taken prior to a typical open ocean voyage. The crew, large or small, of a polar-bound vessel should be thoroughly indoctrinated in the fundamentals of polar operations, utilizing the best information sources available. The subjects covered should include training in ship handling in ice, polar navigation, effects of low temperatures on materials and equipment, damage control procedures, communications problems inherent in polar regions, polar meteorology, sea ice terminology, ice observing and reporting procedures (including classification and codes) and polar survival. Training materials should consist of reports on previous Arctic and Antarctic voyages, sailing directions, ice atlases, training films on polar operations, and U.S. Navy service manuals detailing the recommended procedures to follow during high latitude missions. Various sources of information can be obtained from the Director, National Ice Center, 4251 Suitland Road, Washington, D.C., 20395 and from the Office of Polar Programs, National Science Foundation, Washington, D.C.

The preparation of a vessel for polar operations is of extreme importance and the considerable experience gained from previous operations should be drawn upon to bring the ship to optimum operating condition. At the very least, operations conducted in ice-infested waters require that the vessel's hull and propulsion system undergo certain modifications.

The bow and waterline of the forward part of the vessel should be heavily reinforced. Similar reinforcement should also be considered for the propulsion spaces of the vessel. Cast iron propellers and those made of a bronze alloy do not possess the strength necessary to operate safely in ice. Therefore, it is strongly recommended that propellers made of these materials be replaced by steel. Other desirable features are the absence of vertical sides, deep placement of

the propellers, a blunt bow, metal guards to protect propellers from ice damage, and lifeboats for 150 percent of personnel aboard. The complete list of desirable features depends upon the area of operations, types of ice to be encountered, length of stay in the vicinity of ice, anticipated assistance by icebreakers, and possibly other factors. Strength requirements and the minimum thicknesses deemed necessary for the vessel's frames and additional plating to be used as reinforcement, as well as other procedures needed to outfit a vessel for ice operations, can be obtained from the American Bureau of Shipping. For a more definitive and complete guide to the ice strengthening of ships, the mariner may desire to consult the procedures outlined in Rules for Ice Strengthening of Ships, from the Board of Navigation, Helsinki, Finland.

Equipment necessary to meet the basic needs of the crew and to insure the successful and safe completion of the polar voyage should not be overlooked. A minimum list of essential items should consist of polar clothing and footwear, 100% u/v protection sunglasses, food, vitamins, medical supplies, fuel, storage batteries, antifreeze, explosives, detonators, fuses, meteorological supplies, and survival kits containing sleeping bags, trail rations, firearms, ammunition, fishing gear, emergency medical supplies, and a repair kit.

The vessel's safety depends largely upon the thoroughness of advance preparations, the alertness and skill of its crew, and their ability to make repairs if damage is incurred. Spare propellers, rudder assemblies, and patch materials, together with the equipment necessary to effect emergency repairs of structural damage should be carried. Examples of repair materials needed include quick setting cement, oakum, canvas, timbers, planks, pieces of steel of varying shapes, welding equipment, clamps, and an assortment of nuts, bolts, washers, screws, and nails.

Ice and snow accumulation on the vessel poses a definite capsize hazard. Mallets, baseball bats, ax handles, and scrapers to aid in the removal of heavy accumulations of ice, together with snow shovels and stiff brooms for snow removal should be provided. A live steam line may be useful in removing ice from superstructures.

Navigation in polar waters is at best difficult and, during poor conditions, impossible. Environmental conditions encountered in high latitudes such as fog, storms, compass anomalies, atmospheric effects, and, of course, ice, hinder polar operations. Also, deficiencies in the reliability and detail of hydrographic and geographical information presented on polar navigation charts, coupled with a distinct lack of reliable bathymetry, current, and tidal data, add to the problems of polar navigation. Much work is being carried out in polar regions to improve the geodetic control, triangulation, and quality of hydrographic and topographic information necessary for accurate polar charts. However, until this massive task is completed, the only resource open to the polar navigator, especially during periods of poor environmental conditions, is to rely upon the basic principles of navigation and adapt them to unconventional methods when abnormal situations arise.

Upon the approach to pack ice, a careful decision is needed to determine the best action. Often it is possible to go around the ice, rather than through it. Unless the pack is quite loose, this action usually gains rather than loses time. When skirting an ice field or an iceberg, do so to windward, if a choice is available, to avoid projecting tongues of ice or individual pieces that have been blown away from the main body of ice.

When it becomes necessary to enter pack ice, a thorough examination of the distribution and extent of the ice conditions should be made beforehand from the highest possible location. Aircraft (particularly helicopters) and direct satellite readouts are of great value in determining the nature of the ice to be encountered. The most important features to be noted include the location of open water, such as leads and polynyas, which may be manifested by water sky; icebergs; and the presence or absence of both ice under pressure and rotten ice. Some protection may be offered the propeller and rudder assemblies by trimming the vessel down by the stern slightly (not more than 2–3 feet) prior to entering the ice; however, this precaution usually impairs the maneuvering characteristics of most vessels not specifically built for ice breaking.

Selecting the point of entry into the pack should be done with great care; and if the ice boundary consists of closely packed ice or ice under pressure, it is advisable to skirt the edge until a more desirable point of entry is located. Seek areas with low ice concentrations, areas of rotten ice or those containing navigable leads, and if possible enter from leeward on a course perpendicular to the ice edge. It is also advisable to take into consideration the direction and force of the wind, and the set and drift of the prevailing currents when determining the point of entry and the course followed thereafter. Due to wind induced wave action, ice floes close to the periphery of the ice pack will take on a bouncing motion which can be quite hazardous to the hull of thin-skinned vessels. In addition, note that pack ice will drift slightly to the right of the true wind in the Northern Hemisphere and to the left in the Southern Hemisphere, and that leads opened by the force of the wind will appear perpendicular to the wind direction. If a suitable entry point cannot be located due to less than favorable conditions, patience may be called for. Unfavorable conditions generally improve over a short period of time by a change in the wind, tide, or sea state.

Once in the pack, always try to work with the ice, not against it, and keep moving, but do not rush. Respect the ice but do not fear it. Proceed at slow speed at first, staying in open water or in areas of weak ice if possible. The vessel's speed may be safely increased after it has been ascertained how well it handles under the varying ice conditions encountered. It is better to make good progress in the general direction desired than to fight large thick floes in the exact direction to be made good. However, avoid the temptation to proceed far to one side of the intended track; it is almost always better to back out and seek a more penetrable area.

During those situations when it becomes necessary to back, always do so with extreme caution and *with the rudder amidships*. If the ship is stopped by ice, the first command should be “rudder amidships,” given while the screw is still turning. This will help protect the propeller when backing and prevent ice jamming between rudder and hull. If the rudder becomes ice-jammed, man after steering, establish communications, and *do not* give any helm commands until the rudder is clear. A quick full-ahead burst may clear it. If it does not, try going to “hard rudder” *in the same direction slowly* while turning full or flank speed ahead.

Ice conditions may change rapidly while a vessel is working in pack ice, necessitating quick maneuvering. Conventional vessels, even though ice strengthened, are not built for ice breaking. The vessel should be conned to first attempt to place it in leads or polynyas, giving due consideration to wind conditions. The age, thickness, and size of ice which can be navigated depends upon the type, size, hull strength, and horsepower of the vessel employed. If contact with an ice floe is unavoidable, never strike it a glancing blow. This maneuver may cause the ship to veer off in a direction which will swing the stern into the ice. If possible, seek weak spots in the floe and hit it head-on at slow speed. Unless the ice is rotten or very young, do not attempt to break through the floe, but rather make an attempt to swing it aside as speed is slowly increased. Keep clear of corners and projecting points of ice, but do so without making sharp turns which may throw the stern against the ice, resulting in a damaged propeller, propeller shaft, or rudder. The use of full rudder in non-emergency situations is not recommended because it may swing either the stern or mid-section of the vessel into the ice. This does not preclude use of alternating full rudder (swinging the rudder) aboard ice-breakers as a technique for penetrating heavy ice.

Offshore winds may open relatively ice free navigable coastal leads, but such leads should not be entered without benefit of icebreaker escort. If it becomes necessary to enter coastal leads, narrow straits, or bays, an alert watch should be maintained since a shift in the wind may force drifting ice down upon the vessel. An increase in wind on the windward side of a prominent point, grounded iceberg, or land ice tongue extending into the sea will also endanger a vessel. It is wiser to seek out leads toward the windward side of the main body of the ice pack. In the event that the vessel is under imminent danger of being trapped close to shore by pack ice, immediately attempt to orient the vessel’s bow seaward. This will help to take advantage of the little maneuvering room available in the open water areas found between ice floes. Work carefully through these areas, easing the ice floes aside while maintaining a close watch on the general movement of the ice pack.

If the vessel is completely halted by pack ice, it is best to keep the rudder amidships, and the propellers turning at slow speed. The wash of the propellers will help to clear ice away from the stern, making it possible to back down safely. When the vessel is stuck fast, an attempt first should be made to free the vessel by going full speed astern. If this maneuver proves ineffective, it may be possible to get the vessel’s stern to move slightly, thereby causing the bow to shift, by quickly shifting the rudder from one side to the other while going full speed ahead. Another attempt at going astern might then free the vessel. The vessel may also be freed by either transferring water from ballast tanks, causing the vessel to list, or by alternately flooding and emptying the fore and aft tanks. A heavy weight swung out on the cargo boom might give the vessel enough list to break free. If all these methods fail, the utilization of deadmen (2– to 4–meter lengths of timber buried in holes out in the ice and to which a vessel is moored) and ice anchors (a stockless, single-fluked hook embedded in the ice) may be helpful. With a deadman or ice anchors attached to the ice astern, the vessel may be warped off the ice by winching while the engines are going full astern. If all the foregoing methods fail, explosives placed in holes cut nearly to the bottom of the ice approximately 10 to 12 meters off the beam of the vessel and detonated while the engines are working full astern might succeed in freeing the vessel. A vessel may also be sawed out of the ice if the air temperature is above the freezing point of seawater.

When a vessel becomes so closely surrounded by ice that all steering control is lost and it is unable to move, it is **beset**. It may then be carried by the drifting pack into shallow water or areas containing thicker ice or icebergs with their accompanying dangerous underwater projections. If ice forcibly presses itself against the hull, the vessel is said to be **nipped**, whether or not damage is sustained. When this occurs, the gradually increasing pressure may be capable of holing the vessel’s bottom or crushing the sides. When a vessel is beset or nipped, freedom may be achieved through the careful maneuvering procedures, the physical efforts of the crew, or by the use of explosives similar to those previously detailed. Under severe conditions the mariner’s best ally may be patience since there will be many times when nothing can be done to improve the vessel’s plight until there is a change in meteorological conditions. It may be well to preserve fuel and perform any needed repairs to the vessel and its engines. Damage to the vessel while it is beset is usually attributable to collisions or pressure exerted between the vessel’s hull, propellers, or rudder assembly, and the sharp corners of ice floes. These collisions can be minimized greatly by attempting to align the vessel in such a manner as to insure that the pressure from the surrounding pack ice is distributed as evenly as possible over the hull. This is best accomplished when medium or large ice floes encircle the vessel.

In the vicinity of icebergs, either in or outside of the pack ice, a sharp lookout should be kept and all icebergs given a wide berth. The commanding officers and masters of all vessels, irrespective of their size, should treat all icebergs with great respect. The best locations for lookouts are generally in a crow’s nest, rigged in the foremast or housed in a shelter built specifically for a bow lookout in the eyes of a vessel. Telephone communications between these sites and the navigation bridge on larger vessels will prove in-

valuable. It is dangerous to approach close to an iceberg of any size because of the possibility of encountering underwater extensions, and because icebergs that are disintegrating may suddenly capsize or readjust their masses to new positions of equilibrium. In periods of low visibility the utmost caution is needed at all times. Vessel speed should be reduced and the watch prepared for quick maneuvering. Radar becomes an effective tool in this case, but does not negate the need for trained lookouts.

Since icebergs may have from eight to nine-tenths of their masses below the water surface, their drift is generally influenced more by currents than winds, particularly under light wind conditions. The drift of pack ice, on the other hand, is usually dependent upon the wind. Under these conditions, icebergs within the pack may be found moving at a different rate and in a different direction from that of the pack ice. In regions of strong currents, icebergs should always be given a wide berth because they may travel upwind under the influence of contrary currents, breaking heavy pack in their paths and endangering vessels unable to work clear. In these situations, open water will generally be found to leeward of the iceberg, with piled up pack ice to windward. Where currents are weak and a strong wind predominates, similar conditions will be observed as the wind driven ice pack overtakes an iceberg and piles up to windward with an open water area lying to leeward.

Under ice, submarine operations require knowledge of prevailing and expected sea ice conditions to ensure maximum operational efficiency and safety. The most important ice features are the frequency and extent of downward projections (bummocks and ice keels) from the underside of the ice canopy (pack ice and enclosed water areas from the point of view of the submariner), the distribution of thin ice areas through which submarines can attempt to surface, and the probable location of the outer pack edge where submarines can remain surfaced during emergencies to rendezvous with surface ship or helicopter units.

Bummocks are the subsurface counterpart of hummocks, and **ice keels** are similarly related to ridges. When the physical nature of these ice features is considered, it is apparent that ice keels may have considerable horizontal extent, whereas individual bummocks can be expected to have little horizontal extent. In shallow water lanes to the Arctic Basin, such as the Bering Strait and the adjoining portions of the Bering Sea and Chukchi Sea, deep bummocks and ice keels may leave little vertical room for submarine passage. Widely separated bummocks may be circumnavigated but make for a hazardous passage. Extensive ice areas, with numerous bummocks or ice keels which cross the lane may effectively block both surface and submarine passage into the Arctic Basin.

Bummocks and ice keels may extend downward approximately five times their vertical extent above the ice surface. Therefore, observed ridges of approximately 10 meters may extend as much as 50 meters below sea level. Because of the direct relation of the frequency and vertical extent between these surface features and their subsurface counterparts, aircraft ice reconnaissance should be conducted over a planned submarine cruise track before under ice operations commence.

Skylights are thin places (usually less than 1 meter thick) in the ice canopy, and appear from below as relatively light translucent patches in dark surroundings. The undersurface of a skylight is usually flat; not having been subjected to great pressure. Skylights are called large if big enough for a submarine to attempt to surface through them; that is, have a linear extent of at least 120 meters. Skylights smaller than 120 meters are referred to as small. An ice canopy along a submarine’s track that contains a number of large skylights or other features such as leads and polynyas which permit a submarine to surface more frequently than 10 times in 30 miles, is called **friendly ice**. An ice canopy containing no large skylights or other features which permit a submarine to surface is called **hostile ice**.

3414. Great Lakes Ice

Large vessels have been navigating the Great Lakes since the early 1760’s. This large expanse of navigable water has since become one of the world’s busiest waterways. Due to the northern geographical location of the Great Lakes Basin and its susceptibility to Arctic outbreaks of polar air during winter, the formation of ice plays a major disruptive role in the region’s economically vital marine industry. Because of the relatively large size of the five Great Lakes, the ice cover which forms on them is affected by the wind and currents to a greater degree than on smaller lakes. The Great Lakes’ northern location results in a long ice growth season, which in combination with the effect of wind and current, imparts to their ice covers some of the characteristics and behavior of an Arctic ice pack.

Since the five Great Lakes extend over a distance of approximately 800 kilometers in a north-south direction, each lake is influenced differently by various meteorological phenomena. These, in combination with the fact that each lake also possesses different geographical characteristics, affect the extent and distribution of their ice covers.

The largest, deepest, and most northern of the Great Lakes is Lake Superior. Initial ice formation normally begins at the end of November or early December in harbors and bays along the north shore, in the western portion of the lake and over the shallow waters of Whitefish Bay. As the season progresses, ice forms and thickens in all coastal areas of the lake perimeter prior to extending offshore. This formation pattern can be attributed to a maximum depth in excess of 400 meters and an associated large heat storage capacity that hinders early ice formation in the center of the lake. During a normal winter, ice not under pressure ranges in thickness from 45–85 centimeters. During severe winters, maximum thicknesses are reported to approach 100 centimeters. Winds and currents acting upon the ice have

been known to cause ridging with heights approaching 10 meters. During normal years, maximum ice cover extends over approximately 75% of the lake surface with heaviest ice conditions occurring by early March. This value increases to 95% coverage during severe winters and decreases to less than 20% coverage during a mild winter. Winter navigation is most difficult in the southeastern portion of the lake due to heavy ridging and compression of the ice under the influence of prevailing westerly winds. Break-up normally starts near the end of March with ice in a state of advanced deterioration by the middle of April. Under normal conditions, most of the lake is ice-free by the first week of May.

Lake Michigan extends in a north-south direction over 490 kilometers and possesses the third largest surface area of the five Great Lakes. Depths range from 280 meters in the center of the lake to 40 meters in the shipping lanes through the Straits of Mackinac, and less in passages between island groups. During average years, ice formation first occurs in the shallows of Green Bay and extends eastward along the northern coastal areas into the Straits of Mackinac during the second half of December and early January. Ice formation and accumulation proceeds southward with coastal ice found throughout the southern perimeter of the lake by late January. Normal ice thicknesses range from 10–20 centimeters in the south to 40–60 centimeters in the north. During normal years, maximum ice cover extends over approximately 40% of the lake surface with heaviest conditions occurring in late February and early March. Ice coverage increases to 85–90% during a severe winter and decreases to only 10–15% during a mild year. Coverage of 100% occurs, but rarely. Throughout the winter, ice formed in mid-lake areas tends to drift eastward because of prevailing westerly winds. This movement of ice causes an area in the southern central portion of the lake to remain ice-free throughout a normal winter. Extensive ridging of ice around the island areas adjacent to the Straits of Mackinac presents the greatest hazard to year-round navigation on this lake. Due to an extensive length and north-south orientation, ice formation and deterioration often occur simultaneously in separate regions of this lake. Ice break-up normally begins by early March in southern areas and progresses to the north by early April. Under normal conditions, only 5–10% of the lake surface is ice covered by mid-April with lingering ice in Green Bay and the Straits of Mackinac completely melting by the end of April.

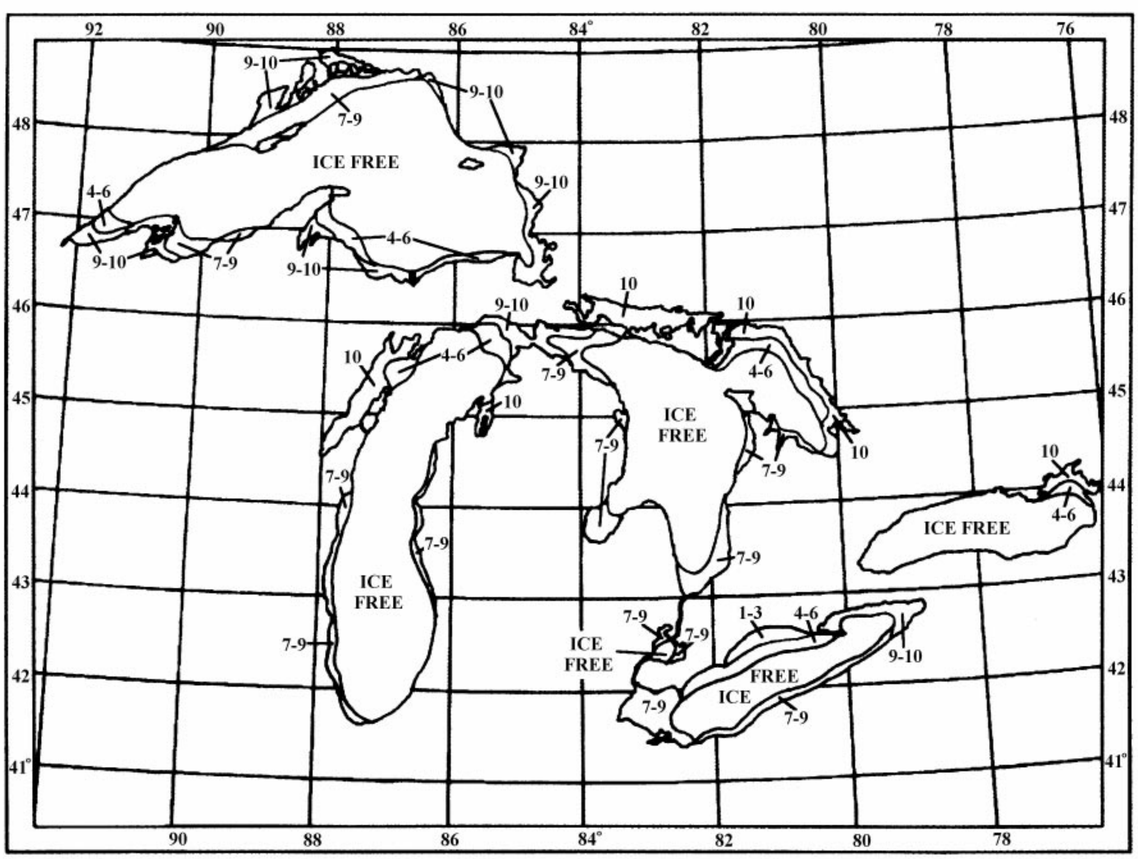


Figure 3414a. Great Lakes maximum ice cover during a mild winter.

Lake Huron, the second largest of the Great Lakes, has maximum depths of 230 and 170 meters in the central basin west of the Bruce peninsula and in Georgian Bay, respectively. The pattern of ice formation in Lake Huron is similar to the north-south progression described in Lake Michigan. Initial ice formation normally begins in the North Channel and along the eastern coast of Saginaw and Georgian Bays by mid-December. Ice rapidly expands into the western and southern coastal areas before extending out into the deeper portions of the lake by late January. Normal ice thicknesses are 45–75 centimeters. During severe winters, maximum ice thicknesses often exceed 100 centimeters with windrows of ridged ice achieving thicknesses of up to 10 meters. During normal years, maximum ice cover occurs in late February with 60% coverage in Lake Huron and nearly 95% coverage in Georgian Bay. These values increase to 85–90% in Lake Huron and nearly 100% in Georgian Bay during severe winters. The percent of lake surface area covered by ice decreases to 20–25% for both bodies of water during mild years. During the winter, ice as a hazard to navigation is of greatest concern in the St. Mary's River/North Channel area and the Straits of Mackinac. Ice break-up normally begins in mid-March in southern coastal areas with melting conditions rapidly spreading northward by early April. A recurring threat to navigation is the southward drift and accumulation of melting ice at the entrance of the St. Clair river. Under normal conditions, the lake becomes ice-free by the first week of May.

The shallowest and most southern of the Great Lakes is Lake Erie. Although the maximum depth nears 65 meters in the eastern portion of the lake, an overall mean depth of only 20 meters results in the rapid accumulation of ice over a short period of time with the onset of winter. Initial ice formation begins in the very shallow western portion of the lake in mid-December with ice rapidly extending eastward by early January. The eastern portion of the lake does not normally become ice covered until late January. During a normal winter, ice thicknesses range from 25–45 centimeters in Lake Erie. During the period of rapid ice growth, prevailing winds and currents routinely move existing ice to the northeastern end of the lake. This accumulation of ice under pressure is often characterized by ridging with maximum heights of 8–10 meters. During a severe winter, initial ice formation may begin in late No-

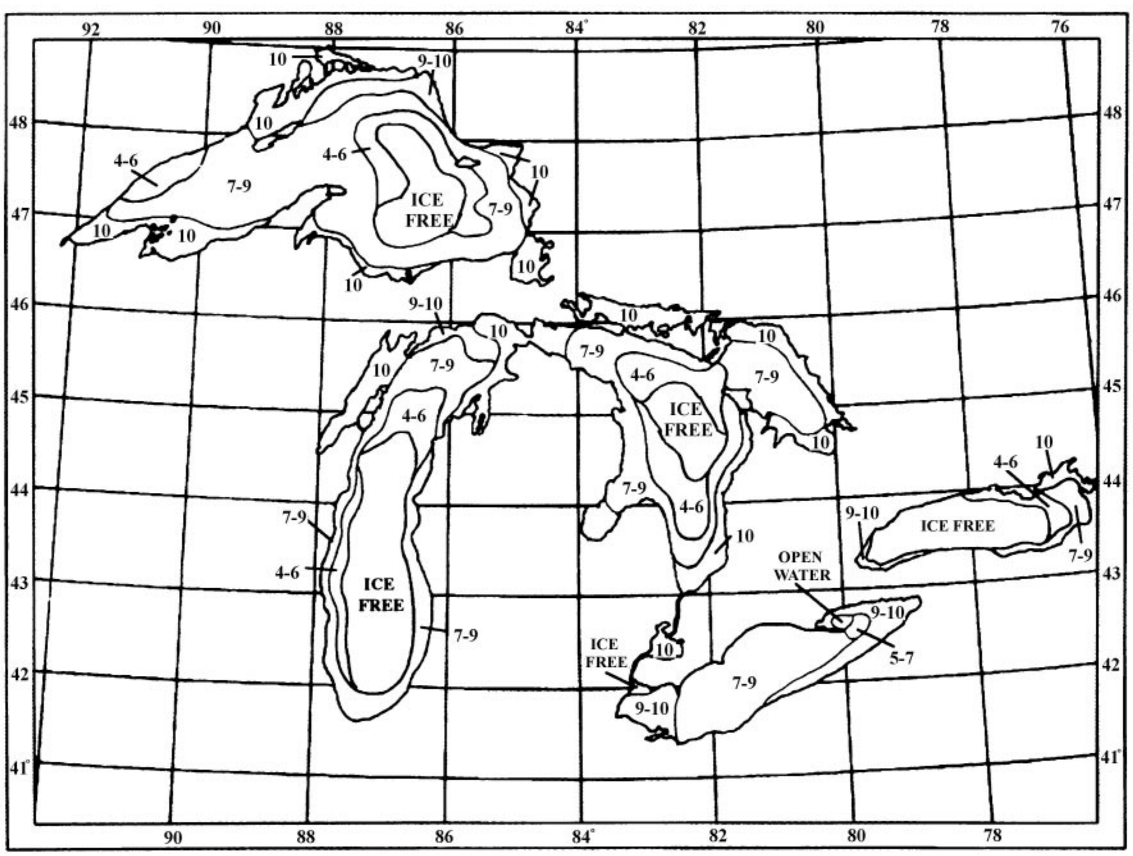


Figure 3414b. Great Lakes maximum ice cover during a normal winter.

vember with maximum seasonal ice thicknesses exceeding 70 centimeters. Since this lake reacts rapidly to changes in air temperature, the variability of percent ice cover is the greatest of the five Great Lakes. During normal years, ice cover extends over approximately 90–95% of the lake surface by mid to late February. This value increases to nearly 100% during a severe winter and decreases to 30% ice coverage during a mild year. Lake St. Clair, on the connecting waterway to Lake Huron, is normally consolidated from the middle of January until early March. Ice break-up normally begins in the western portion of Lake Erie in early March with the lake becoming mostly ice-free by the middle of the month. The exception to this rapid deterioration is the extreme eastern end of the lake where ice often lingers until early May.

Lake Ontario has the smallest surface area and second greatest mean depth of the Great Lakes. Depths range from 245 meters in the southeastern portion of the lake to 55 meters in the approaches to the St. Lawrence River. Like Lake Superior, a large mean depth gives Lake Ontario a large heat storage capacity which, in combination with a small surface area, causes Lake Ontario to respond slowly to changing meteorological conditions. As a result, this lake produces the smallest amount of ice cover found on any of the Great Lakes. Initial ice formation normally begins from the middle to late December in the Bay of Quinte and extends to the western coastal shallows near the mouth of the St. Lawrence River by early January. By the first half of February, Lake Ontario is almost 20% ice covered with shore ice lining the perimeter of the lake. During normal years, ice cover extends over approximately 25% of the lake surface by the second half of February. During this period of maximum ice coverage, ice is typically concentrated in the northeastern portion of the lake by prevailing westerly winds and currents. Ice coverage can extend over 50–60% of the lake surface during a severe winter and less than 10% during a mild year. Level lake ice thicknesses normally fall within the 20–60 centimeter range with occasional reports exceeding 70 centimeters during severe years. Ice break-up normally begins in early March with the lake generally becoming ice-free by mid-April.

The maximum ice cover distribution attained by each of the Great lakes for mild, normal and severe winters is

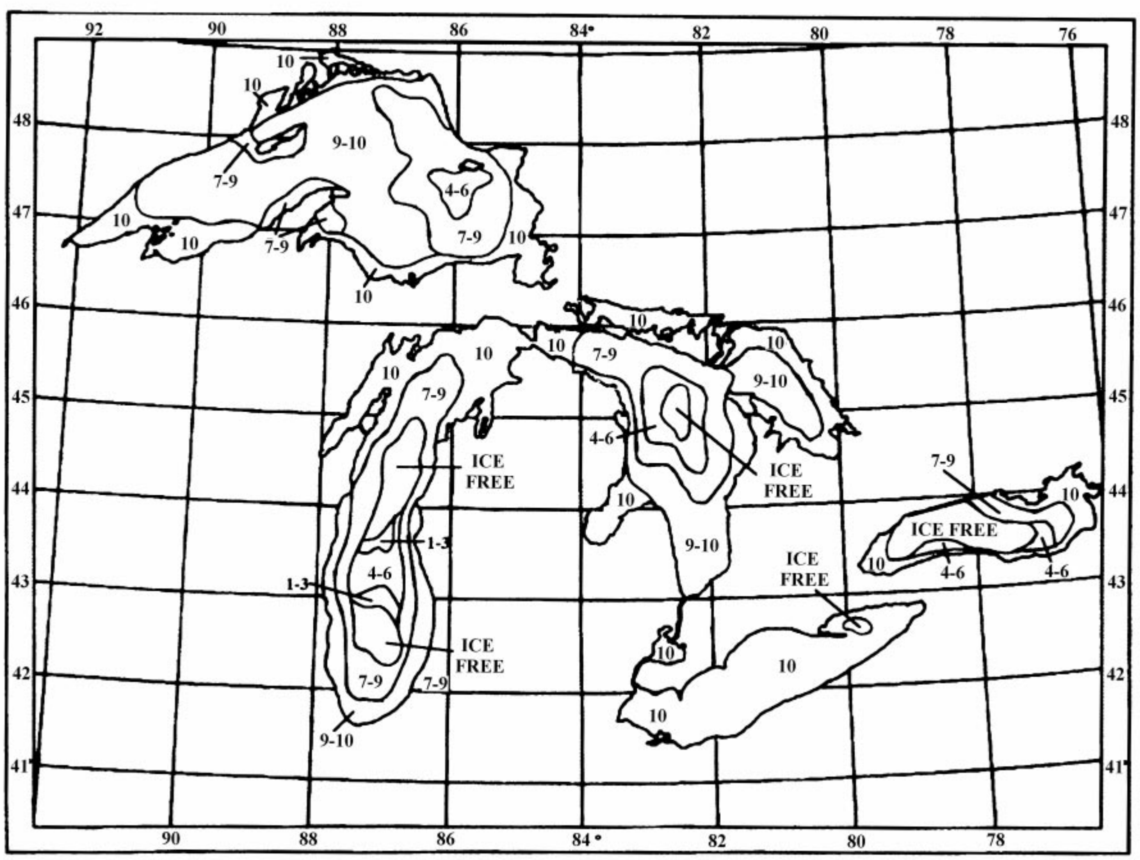


Figure 3414c. Great Lakes maximum ice cover during a severe winter.

shown in Figure 3414a, Figure 3414b and Figure 3414c. It should be noted that although the average maximum ice cover for each lake appears on the same chart, the actual occurrence of each distribution takes place during the time periods described within the preceding narratives.

Information concerning ice analyses and forecasts for the Great Lakes can be obtained from the Director, National Ice Center, 4251 Suitland Road, Washington D.C. 20395 and the National Weather Service Forecast Office located in Cleveland, Ohio. Ice climatological information can be obtained from the Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan.

ICE INFORMATION SERVICES

3415. Importance Of Ice Information

Advance knowledge of ice conditions to be encountered and how these conditions will change over specified time periods are invaluable for both the planning and operational phases of a voyage to the polar regions. Branches of the United States Federal Government responsible for providing operational ice products and services for safety of navigation include the Departments of Defense (U.S. Navy), Commerce (NOAA), and Transportation (U.S. Coast Guard). Manpower and resources from these agencies comprise the National Ice Center (NIC), which replaced the Navy/NOAA Joint Ice Center. The NIC provides ice products and services to U.S. Government military and civilian interests. Routine and tailored ice products of the NIC shown in Table 3417 can be separated into two categories: a) analyses which describe current ice conditions and b) forecasts which define the expected changes in the existing ice cover over a specified time period.

The content of sea ice analyses is directly dependent upon the planned use of the product, the required level of detail, and the availability of on-site ice observations and/or remotely-sensed data. Ice analyses are produced by blending relatively small numbers of visual ice observations from ships, shore stations and fixed wing aircraft with increasing amounts of remotely sensed data. These data include aircraft and satellite imagery in the visual, infrared, passive microwave and radar bands. The efficient receipt and accurate interpretation of these data are critical to producing a near real-time (24–48 hour old) analysis or "picture" of the ice cover. In general, global and regional scale ice analyses depict ice edge location, ice concentrations within the pack and the ice stages of development or thickness. Local scale ice analyses emphasize the location of thin ice covered or open water leads/polynyas, areas of heavy compression, frequency of ridging, and the presence or absence of dangerous multiyear ice and/or icebergs. The parameters defined in this tactical scale analysis are considered critical to both safety of navigation and the efficient routing of ships through the sea ice cover.

3416. Ice Forecasts And Observations

Sea ice forecasts are routinely separated into four temporal classes: short-term (24–72 hour), weekly (5–7 days), monthly (15–30 days) and seasonal (60–90 days) forecasts. Short-term forecasts are generally paired with local-scale ice analyses and focus on changes in the ice cover based on ice drift, ice formation and ablation, and divergent/convergent processes. Of particular importance are the predicted location of the ice edge and the presence or absence of open water polynyas and coastal/flaw leads. The accurate prediction of the location of these ice features are important for both ice avoidance and ice exploitation purposes.

Similar but with less detail, weekly ice forecasts also emphasize the change in ice edge location and concentration areas within the pack. The National Ice Center presently employs several prediction models to produce both short-term and weekly forecasts. These include empirical models which relate ice drift with geostrophic winds and a coupled dynamic/thermodynamic model called the Polar Ice Prediction System (PIPS). Unlike earlier models, the latter accounts for the effects of ice thickness, concentration, and growth on ice drift.

Monthly ice forecasts predict changes in overall ice extent and are based upon the predicted trends in air temperatures, projected paths of transiting low pressure systems, and continuity of ice conditions.

Seasonal or 90 day ice forecasts predict seasonal ice severity and the projected impact on annual shipping operations. Of particular interest to the National Ice Center are seasonal forecasts for the Alaskan North Slope, Baffin Bay for the annual resupply of Thule, Greenland, and Ross Sea/McMurdo Sound in Antarctica. Seasonal forecasts are also important to Great Lakes and St. Lawrence Seaway shipping interests.

Ice services provided to U.S. Government agencies upon request include aerial reconnaissance for polar shipping operations, ship visits for operational briefing and training, and optimum track ship routing (OTSR) recommendations through ice-infested seas. Commercial operations interested in ice products may obtain routinely produced ice products from the National Ice Center as well as ice analyses and forecasts for Alaskan waters from the National Weather Service Forecast Office in Anchorage, Alaska. Specific information on request procedures, types of ice products, ice services, methods of product dissemination and ship weather support is contained in the publication "Environmental Services for Polar Operations" prepared and distributed by the Director, National Ice Center, 4251 Suitland Road, Washington, D.C., 20395.

The U.S. Coast Guard has an additional responsibility, sep-

arate from the National Ice Center, for providing icebreaker support for polar operations and the administration and operations of the International Ice Patrol (IIP). Inquiries for further information on these subjects should be sent to Commandant (G–N10–3), 2100 Second Street S.W., Washington D.C. 20593.

Other countries which provide sea ice information services are as follows: Arctic – Canada, Denmark (Greenland), Japan (Seas of Okhotsk, Japan and Bo Hai), Iceland, Norway, Russia and the United Kingdom; Antarctic – Argentina, Australia, Chile, Germany, Japan, and Russia; and Baltic – Finland, Germany, Sweden and Russia. Except for the United States, the ice information services of all countries place specific focus upon ice conditions in territorial seas or waters adjacent to claims on the Antarctic continent. The National Ice Center of the United States is the only organization which provides global ice products and services. Names and locations of foreign sea ice service organizations can be found in “Sea Ice Information Services in the World,” WMO Publication No. 574.

Mariners operating in and around sea ice can contribute substantially to increasing the knowledge of synoptic ice conditions, and therefore the accuracy of subsequent ice products by routinely taking and distributing ice observations. The code normally used by personnel trained only to take meteorological observations consists of a five character group appended to the World Meteorological Organization (WMO) weather reporting code: FM 13–X SHIP –Report of Surface Observation from a Sea Station. The five digit ICE group has the following format: ICE + $c_i s_i b_i D_i z_i$. In general, the symbols represent:

c	=	total concentration of sea ice.
s	=	stage of development of sea ice.
b	=	ice of land origin (number of icebergs, growlers and bergy bits).
D	=	bearing of principal ice edge.
z	=	present situation and trend of conditions over three preceding hours.

The complete format and tables for the code are described in the WMO publication “Manual on Codes”, Volume 1, WMO No. 306. This publication is available from the Secretariat of the World Meteorological Organization, Geneva, Switzerland.

A more complete and detailed reporting code (ICEOB) has been in use since 1972 by vessels reporting to the U.S. National Ice Center. 1993 revisions to this code and the procedures for use are described in the “Ice Observation Handbook” prepared and distributed by the Director, National Ice Center, 4251 Suitland Road, Washington D.C., 20395.

All ice observation codes make use of special nomenclature which is precisely defined in several languages by the WMO publication “Sea Ice Nomenclature”, WMO No. 259, TP 145. This publication, available from the Secretariat of the WMO, contains descriptive definitions along with photography of most ice features. This publication is very useful for vessels planning to submit ice observations.

3417. Distribution Of Ice Products And Services

The following is intended as a brief overview of the distribution methods for NIC products and services. For detailed information the user should consult the publications discussed in section 3416 or refer specific inquiries to Director, National Ice Center, 4251 Suitland Road, FOB #4, Room 2301, Washington, D.C. 20395 or call (301) 763–1111 or –2000. Facsimile inquiries can be phoned to (301) 763–1366 and will generally be answered by mail, therefore addresses must be included. NIC ice product distribution methods are as follows:

1. Autopolling: Customer originated menu-driven facsimile product distribution system. Call (301) 763–3190/3191 for menu directions or (301) 763–5972 for assignment of Personal Identification Number (PIN).
2. Autodin: Alphanumeric message transmission to U.S. Government organizations or vessels. Address is NAVICECEN Suitland MD.
3. OMNET/SCIENCENET: electronic mail and bulletin board run by OMNET, Inc. (617) 265–9230. Product request messages may be sent to mailbox NATIONAL.ICE.CTR. Ice products are routinely posted on bulletin board SEA.ICE.
4. INTERNET: Product requests may be forwarded to electronic mail address which is available by request from the NIC at (301) 763–5972.
5. Mail Subscription: For weekly Arctic and Antarctic sea ice analysis charts from the National Climatic Data Center, NESDIS, NOAA, 37 Battery Park Ave., Asheville, NC, 28801–2733. Call (704) 271–4800 with requests for ice products.
6. Mail: Annual ice atlases and multiyear ice climatologies are available either from the National Ice Center (if in stock) or from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA, 22161. Call (703) 487–4600 for sales service desk. Digital files (in SIGRID format) of weekly NIC ice analyses may be obtained from the National Snow and Ice Data Center, CIRES, Box 449, University of Colorado, Boulder, Colorado 80309. Call (303) 492–5171 for information.

NAVAL ICE CENTER PRODUCTS

PRODUCT	*FREQUENCY*	*FORMAT*
GLOBAL SCALE		
Eastern Arctic Analysis/Fcst	Wed	Fax Chart
Western Arctic Analysis/Fcst	Tue	Fax Chart
Antarctic Analysis	Thu	Fax Chart
South Ice Limit-East Arctic	Wed	Posted to OMNET
South Ice Limit-West Arctic	Tue	Posted to OMNET
North Ice Limit-Antarctic	Mon	Fax Chart
30 Day Forecast-East Arctic	1st & 15th of month	Fax Chart
30 Day Forecast-West Arctic	1st & 15th of month	Fax Chart
East Arctic Seasonal Outlook	Annually (15 May)	Booklet
West Arctic Seasonal Outlook	Annually (15 May)	Booklet
REGIONAL SCALE		
Alaska Regional Analysis	Tue & Fri	Fax Chart
Great Lakes Analysis	15 Dec–01 May (Mon, Wed, Fri)	Fax Chart
30 Day Forecast-Gt Lakes	15 Nov–15 Apr (1st & 15th of Mo.)	Fax Chart
St. Mary’s River Analysis	01 Jan– 01 May (Mon, Wed, Fri)	Fax Chart
Ross Sea/McMurdo Sound	Annually	Booklet
Seasonal Outlook	(30 Oct)	Booklet
Gt. Lakes Seasonal Outlook	Annually (1 Dec)	Fax Chart
LOCAL SCALE		
Large-Scale Analysis-User-Defined Area	Thrice Weekly	Fax Chart

Table 3417. Products produced by National Ice Center.

CHAPTER 35

WEATHER ELEMENTS

GENERAL DESCRIPTION OF THE ATMOSPHERE

3500. Introduction

Weather is the state of the earth's atmosphere with respect to temperature, humidity, precipitation, visibility, cloudiness, and other factors. **Climate** refers to the average long-term meteorological conditions of a place or region.

All weather may be traced to the effect of the sun on the earth. Most changes in weather involve large-scale horizontal motion of air. Air in motion is called **wind**. This motion is produced by differences of atmospheric pressure, which are attributable both to differences of temperature and the nature of the motion itself.

Weather is of vital importance to the mariner. The wind and state of the sea affect dead reckoning. Reduced visibility limits piloting. The state of the atmosphere affects electronic navigation and radio communication. If the skies are overcast, celestial observations are not available; and under certain conditions refraction and dip are disturbed. When wind was the primary motive power, knowledge of the areas of favorable winds was of great importance. Modern vessels are still affected considerably by wind and sea.

3501. The Atmosphere

The **atmosphere** is a relatively thin shell of air, water vapor, and suspended particulates surrounding the earth. Air is a mixture gases and, like any gas, is elastic and highly compressible. Although extremely light, it has a definite weight which can be measured. A cubic foot of air at standard sea-level temperature and pressure weighs 1.22 ounces, or about $^{1}/_{817}$th the weight of an equal volume of water. Because of this weight, the atmosphere exerts a pressure upon the surface of the earth of about 15 pounds per square inch.

As altitude increases, air pressure decreases due to the decreased weight of air above. With less pressure, the density decreases. More than three-fourths of the air is concentrated within a layer averaging about 7 statute miles thick, called the **troposphere**. This is the region of most "weather," as the term is commonly understood.

The top of the troposphere is marked by a thin transition zone called the **tropopause**, immediately above which is the **stratosphere**. Beyond this lie several other layers having distinctive characteristics. The average height of the tropopause ranges from about 5 miles or less at high latitudes to about 10 miles at low latitudes.

The **standard atmosphere** is a conventional vertical structure of the atmosphere characterized by a standard sea-level pressure of 1013.25 millibars of mercury (29.92 inches) and a sea-level air temperature of 15° C (59° F). The temperature decreases with height (i.e., **standard lapse rate**) being a uniform 2° C (3.6° F) per thousand feet to 11 kilometers (36,089 feet) and thereafter remains constant at –56.5° C (69.7° F).

Research has indicated that the jet stream is important in relation to the sequence of weather. The **jet stream** refers to relatively strong (≤60 knots) quasi-horizontal winds, usually concentrated within a restricted layer of the atmosphere. There are two commonly known jet streams. The **sub-tropical jet stream (STJ)** occurs in the region of 30°N during the northern hemisphere winter, decreasing in summer. The core of highest winds in the STJ is found at about 12km altitude (40,000 feet) an in the region of 70°W, 40°E, and 150°E, although considerable variability is common. The **polar frontal jet stream (PFJ)** is found in middle to upper-middle latitudes and is discontinuous and variable. Maximum jet stream winds have been measured by weather balloons at 291 knots.

3502. General Circulation Of The Atmosphere

The heat required to warm the air is supplied originally by the sun. As radiant energy from the sun arrives at the earth, about 29 percent is reflected back into space by the earth and its atmosphere, 19 percent is absorbed by the atmosphere, and the remaining 52 percent is absorbed by the surface of the earth. Much of the earth's absorbed heat is radiated back into space. Earth's radiation is in comparatively long waves relative to the short-wave radiation from the sun because it emanates from a cooler body. Long-wave radiation, readily absorbed by the water vapor in the air, is primarily responsible for the warmth of the atmosphere near the earth's surface. Thus, the atmosphere acts much like the glass on the roof of a greenhouse. It allows part of the incoming solar radiation to reach the surface of the earth but is heated by the terrestrial radiation passing outward. Over the entire earth and for long periods of time, the total outgoing energy must be equivalent to the incoming energy (minus any converted to another form and retained), or the temperature of the earth and its atmosphere would steadily increase or decrease. In local areas, or over relatively short periods of time, such a balance is not required, and in fact

does not exist, resulting in changes such as those occurring from one year to another, in different seasons and in different parts of the day.

The more nearly perpendicular the rays of the sun strike the surface of the earth, the more heat energy per unit area is received at that place. Physical measurements show that in the tropics, more heat per unit area is received than is radiated away, and that in polar regions, the opposite is true. Unless there were some process to transfer heat from the tropics to polar regions, the tropics would be much warmer than they are, and the polar regions would be much colder. Atmospheric motions bring about the required transfer of heat. The oceans also participate in the process, but to a lesser degree.

If the earth had a uniform surface and did not rotate on its axis, with the sun following its normal path across the sky (solar heating increasing with decreasing latitude), a simple circulation would result, as shown in Figure 3502a. However, the surface of the earth is far from uniform, being covered with an irregular distribution of land and water. Additionally, the earth rotates about its axis so that the portion heated by the sun continually changes. In addition, the axis of rotation is tilted so that as the earth moves along its orbit about the sun, seasonal changes occur in the exposure of specific areas to the sun's rays, resulting in variations in the heat balance of these areas. These factors, coupled with others, result in constantly changing large-scale movements of air. For example, the rotation of the earth exerts an apparent force, known as Coriolis force, which diverts the air from a direct path between high and low pressure areas. The diversion of the air is toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere. At some distance above the surface of the earth, the wind tends to blow along lines connecting points of equal pressure called **isobars**. The wind is called a **geostrophic wind** if the isobars are straight (great circles) and a **gradient wind** if they are curved. Near the surface of the earth, friction tends to divert the wind from the isobars toward the center of low pressure. At sea, where friction is less than on land, the wind follows the isobars more closely.

A simplified diagram of the general circulation pattern is shown in Figure 3502b. Figure 3502c and Figure 3502d give a generalized picture of the world's pressure distribution and wind systems as actually observed.

A change in pressure with horizontal distance is called a **pressure gradient**. It is maximum along a normal (perpendicular) to the isobars. A force results which is called **pressure gradient force** and is always directed from high to low pressure. Speed of the wind is approximately proportional to this pressure gradient.

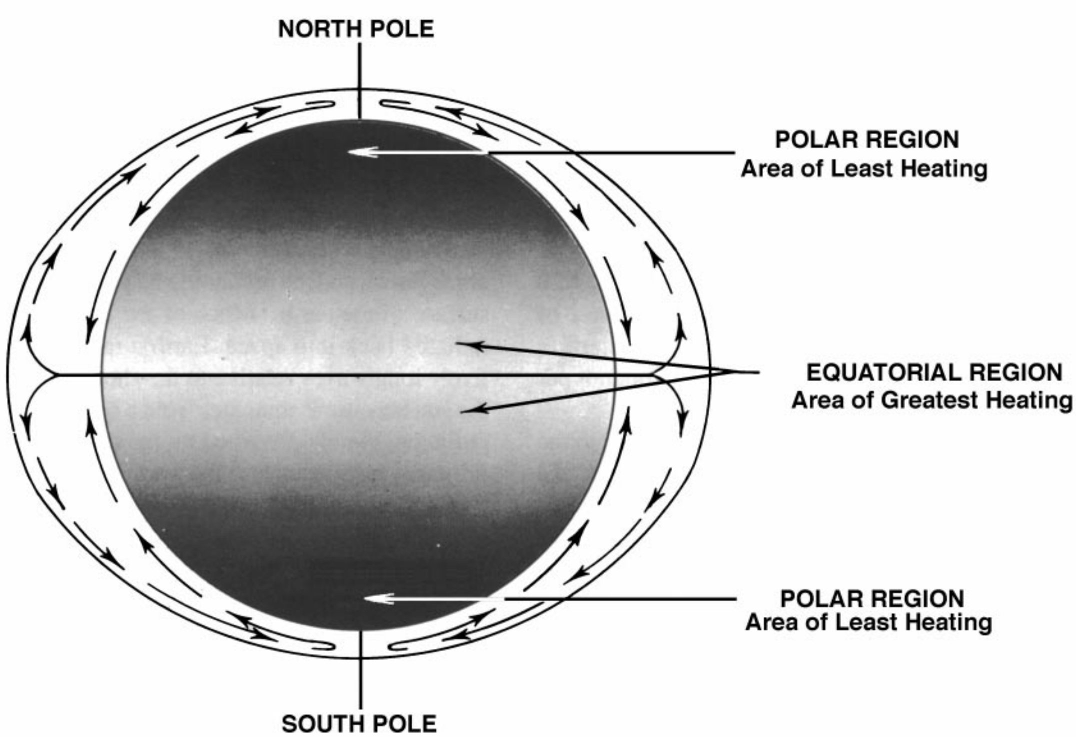


Figure 3502a. Ideal atmospheric circulation for a uniform and nonrotating earth.

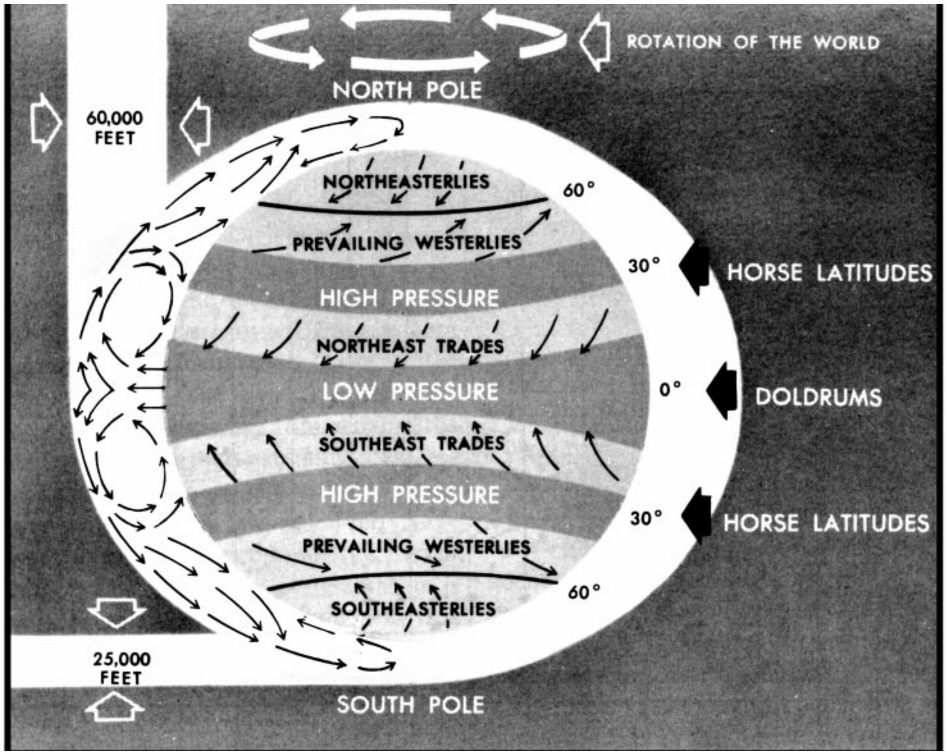


Figure 3502b. Simplified diagram of the general circulation of the atmosphere.

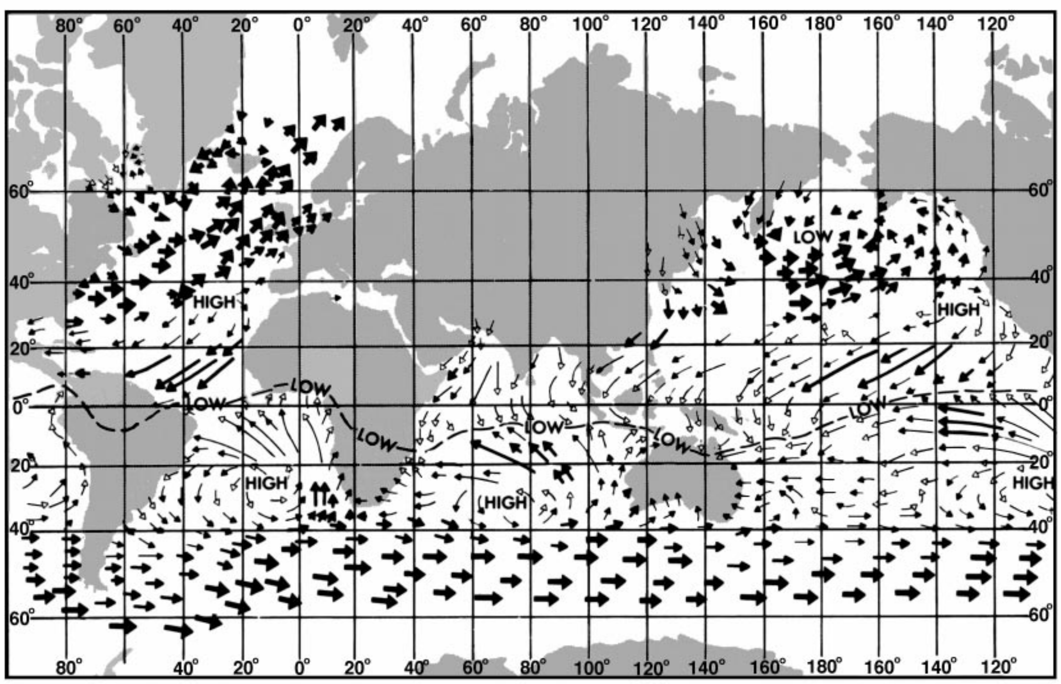


Figure 3502c. Generalized pattern of actual surface winds in January and February.

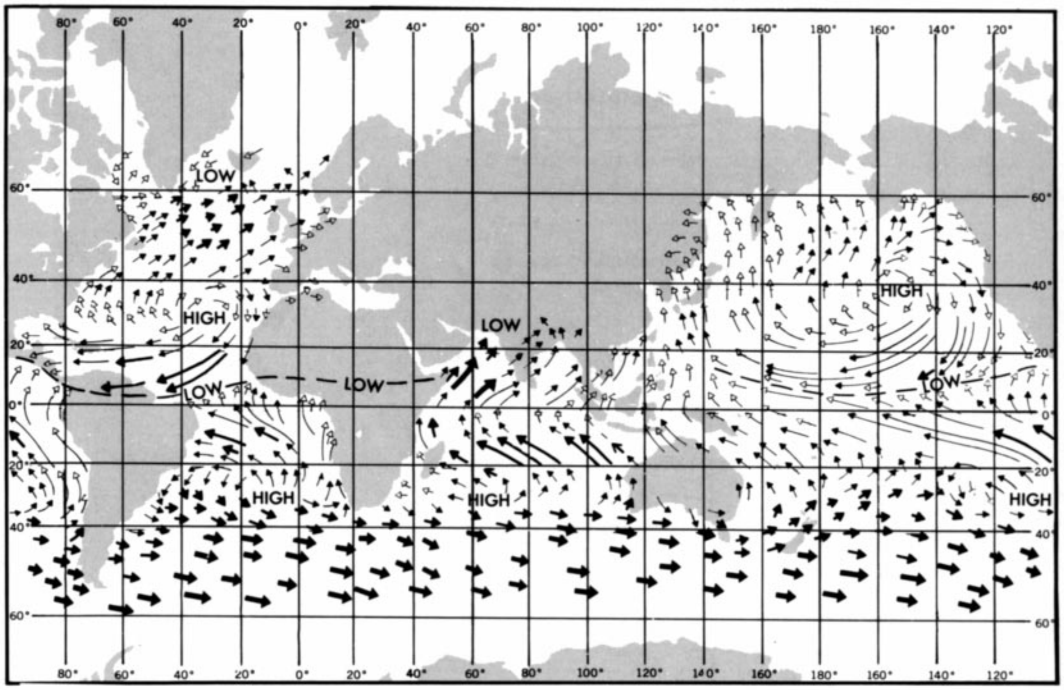


Figure 3502d. Generalized pattern of actual surface winds in July and August. (See key with Figure 3502c.)

MAJOR WIND PATTERNS

3503. The Doldrums

A belt of low pressure at the earth's surface near the equator known as the **doldrums** occupies a position approximately midway between high pressure belts at about latitude 30° to 35° on each side. Except for significant intradiurnal changes, the atmospheric pressure along the equatorial low is almost uniform. With minimal pressure gradient, wind speeds are light and directions are variable. Hot, sultry days are common. The sky is often overcast, and showers and thundershowers are relatively frequent; in these atmospherically unstable areas, brief periods of strong wind occur.

The doldrums occupy a thin belt near the equator, the eastern part in both the Atlantic and Pacific being wider than the western part. However, both the position and extent of the belt vary with longitude and season. During all seasons in the Northern Hemisphere, the belt is centered in the eastern Atlantic and Pacific; however, there are wide excursions of the doldrum regions at longitudes with considerable landmass. On the average, the position is at 5°N, frequently called the **meteorological equator**.

3504. The Trade Winds

The trade winds at the surface blow from the belts of high pressure toward the equatorial belts of low pressure. Because of the rotation of the earth, the moving air is deflected toward the west. Therefore, the trade winds in the Northern Hemisphere are from the northeast and are called the **northeast trades**, while those in the Southern Hemisphere are from the southeast and are called the **southeast trades**. The trade-wind directions are best defined over eastern ocean areas.

The trade winds are generally considered among the most constant of winds, blowing for days or even weeks with little change of direction or speed. However, at times they weaken or shift direction, and there are regions where the general pattern is disrupted. A notable example is found in the island groups of the South Pacific, where the trades are practically nonexistent during January and February. Their best development is attained in the South Atlantic and in the South Indian Ocean. In general, they are stronger during the winter than during the summer season.

In July and August, when the belt of equatorial low pressure moves to a position some distance north of the equator, the southeast trades blow across the equator, into the Northern Hemisphere, where the earth's rotation diverts them toward the right, causing them to be southerly and southwesterly winds. The "southwest monsoons" of the African and Central American coasts originate partly in these diverted southeast trades.

Cyclones from the middle latitudes rarely enter the regions of the trade winds, although tropical cyclones originate within these areas.

3505. The Horse Latitudes

Along the poleward side of each trade-wind belt, and cor-

responding approximately with the belt of high pressure in each hemisphere, is another region with weak pressure gradients and correspondingly light, variable winds. These are called the **horse latitudes**, apparently so named because becalmed sailing ships threw horses overboard in this region when water supplies ran short. The weather is generally good although low clouds are common. Compared to the doldrums, periods of stagnation in the horse latitudes are less persistent. The difference is due primarily to the rising currents of warm air in the equatorial low, which carry large amounts of moisture. This moisture condenses as the air cools at higher levels, while in the horse latitudes the air is apparently descending and becoming less humid as it is warmed at lower heights.

3506. The Prevailing Westerlies

On the poleward side of the high pressure belt in each hemisphere, the atmospheric pressure again diminishes. The currents of air set in motion along these gradients toward the poles are diverted by the earth's rotation toward the east, becoming southwesterly winds in the Northern Hemisphere and northwesterly in the Southern Hemisphere. These two wind systems are known as the **prevailing westerlies** of the temperate zones.

In the Northern Hemisphere this relatively simple pattern is distorted considerably by secondary wind circulations, due primarily to the presence of large landmasses. In the North Atlantic, between latitudes 40° and 50°, winds blow from some direction between south and northwest during 74 percent of the time, being somewhat more persistent in winter than in summer. They are stronger in winter, too, averaging about 25 knots (Beaufort 6) as compared with 14 knots (Beaufort 4) in the summer.

In the Southern Hemisphere the westerlies blow throughout the year with a steadiness approaching that of the trade winds. The speed, though variable, is generally between 17 and 27 knots (Beaufort 5 and 6). Latitudes 40°S to 50°S (or 55°S) where these boisterous winds occur, are called the **roaring forties**. These winds are strongest at about latitude 50°S.

The greater speed and persistence of the westerlies in the Southern Hemisphere are due to the difference in the atmospheric pressure pattern, and its variations, from the Northern Hemisphere. In the comparatively landless Southern Hemisphere, the average yearly atmospheric pressure diminishes much more rapidly on the poleward side of the high pressure belt, and has fewer irregularities due to continental interference, than in the Northern Hemisphere.

3507. Polar Winds

Partly because of the low temperatures near the geographical poles of the earth, the surface pressure tends to remain higher than in surrounding regions, since cold air is more dense than warm air. Consequently, the winds blow outward from the poles, and are deflected westward by the rotation of the earth, to become **northeasterlies** in the Arctic, and **southeasterlies** in the Antarctic. Where the polar easterlies meet the prevailing westerlies, near 50°N and 50°S on the average, a discontinuity in temperature and wind exists. This discontinuity is called the **polar front**. Here the warmer low-latitude air ascends over the colder polar air creating a zone of cloudiness and precipitation.

In the Arctic, the general circulation is greatly modified by surrounding landmasses. Winds over the Arctic Ocean are somewhat variable, and strong surface winds are rarely encountered.

In the Antarctic, on the other hand, a high central landmass is surrounded by water, a condition which augments, rather than diminishes, the general circulation. The high pressure, although weaker than in the horse latitudes, is stronger than in the Arctic, and of great persistence especially in eastern Antarctica. The cold air from the plateau areas moves outward and downward toward the sea and is deflected toward the west by the earth's rotation. The winds remain strong throughout the year, frequently attaining hurricane force near the base of the mountains. These are some of the strongest surface winds encountered anywhere in the world, with the possible exception of those in well-developed tropical cyclones.

3508. Modifications Of The General Circulation

The general circulation of the atmosphere is greatly modified by various conditions.

The high pressure in the horse latitudes is not uniformly distributed around the belts, but tends to be accentuated at several points, as shown in Figure 3502c and Figure 3502d. These semi-permanent highs remain at about the same places with great persistence.

Semi-permanent lows also occur in various places, the most prominent ones being west of Iceland, and over the Aleutians (winter only) in the Northern Hemisphere, and in the Ross Sea and Weddell Sea in the Antarctic areas. The regions occupied by these semi-permanent lows are sometimes called the graveyards of the lows, since many lows move directly into these areas and lose their identity as they merge with and reinforce the semi-permanent lows. The low pressure in these areas is maintained largely by the migratory lows which stall there, with topography also important, especially in Antarctica.

Another modifying influence is land, which undergoes greater temperature changes than does the sea. During the summer, a continent is warmer than its adjacent oceans. Therefore, low pressures tend to prevail over the land. If a climatological belt of high pressure encounters a continent, its pattern is distorted or interrupted, whereas a belt of low pressure is intensified over the same area. In winter, the opposite effect takes place, belts of high pressure being intensified over land and those of low pressure being

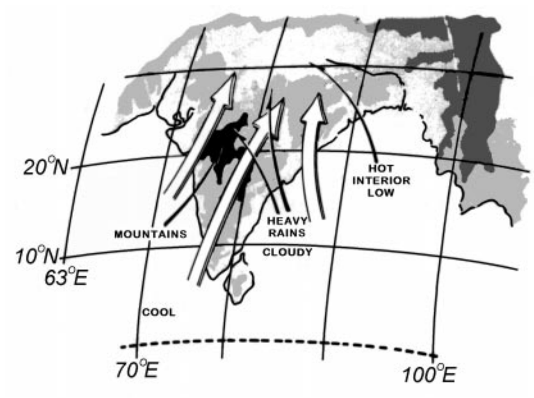


Figure 3508a. The summer monsoon.

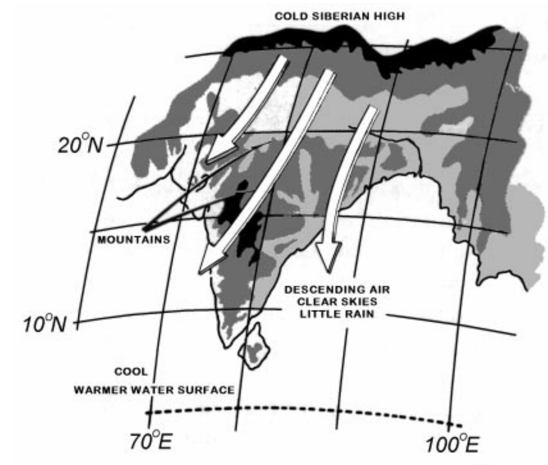


Figure 3508b. The winter monsoon.

weakened.

The most striking example of a wind system produced by the alternate heating and cooling of a landmass is the **monsoon** (seasonal wind) of the China Sea and Indian Ocean. A portion of this effect is shown in Figure 3508a and Figure 3508b. In the summer, low pressure prevails over the warm continent of Asia, and relatively higher pressure prevails over the adjacent sea. Between these two systems the wind blows in a nearly steady direction. The lower portion of the pattern is in the Southern Hemisphere, extending to about 10° south latitude. Here the rotation of the earth causes a deflection to the left, resulting in southeasterly winds. As they cross the equator, the deflection is in the opposite direction, causing them to curve toward the right, becoming southwesterly winds. In the winter, the positions of high and low pressure areas are interchanged, and the direction of flow is reversed.

In the China Sea, the summer monsoon blows from the southwest, usually from May to September. The strong winds are accompanied by heavy squalls and thunderstorms, the rainfall being much heavier than during the winter monsoon. As the season advances, squalls and rain become less frequent. In some places the wind becomes a light breeze which is unsteady in direction, or stops altogether, while in other places it continues almost undiminished, with changes in direction or calms being infrequent. The winter monsoon blows from the northeast, usually from October to April. It blows with a steadiness similar to that of the trade winds, often attaining the speed of a moderate gale (28–33 knots). Skies are generally clear during this season, and there is relatively little rain.

The general circulation is further modified by winds of cyclonic origin and various local winds. Some common local winds are listed by local name below.

Abroholos	A squall frequent from May through August between Cabo de Sao Tome and Cabo Frio on the coast of Brazil.
Bali wind	A strong east wind at the eastern end of Java.
Barat	A heavy northwest squall in Manado Bay on the north coast of the island of Celebes, prevalent from December to February.
Barber	A strong wind carrying damp snow or sleet and spray that freezes upon contact with objects, especially the beard and hair.
Bayamo	A violent wind blowing from the land on the south coast of Cuba, especially near the Bight of Bayamo.
Bentu de Soli	An east wind on the coast of Sardinia.
Bora	A cold, northerly wind blowing from the Hungarian basin into the Adriatic Sea. See also FALL WIND.
Borasco	A thunderstorm or violent squall, especially in the Mediterranean.
Brisa, Briza	1. A northeast wind which blows on the coast of South America or an east wind which blows on Puerto Rico during the trade wind season. 2. The northeast monsoon in the Philippines.
Brisote	The northeast trade wind when it is blowing stronger than usual on Cuba.
Brubu	A name for a squall in the East Indies.
Bull's Eye Squall	A squall forming in fair weather,

Bull's Eye Squall (continued)	characteristic of the ocean off the coast of South Africa. It is named for the peculiar appearance of the small isolated cloud marking the top of the invisible vortex of the storm.
Cape Doctor	The strong southeast wind which blows on the South African coast. Also called the DOCTOR.
Caver, Kaver	A gentle breeze in the Hebrides.
Chubasco	A violent squall with thunder and lightning, encountered during the rainy season along the west coast of Central America.
Churada	A severe rain squall in the Mariana Islands during the northeast monsoon. They occur from November to April or May, especially from January through March.
Cierzo	See MISTRAL.
Contrastes	Winds a short distance apart blowing from opposite quadrants, frequent in the spring and fall in the western Mediterranean.
Cordonazo	The "Lash of St. Francis." Name applied locally to southerly hurricane winds along the west coast of Mexico. It is associated with tropical cyclones in the southeastern North Pacific Ocean. These storms may occur from May to November, but ordinarily affect the coastal areas most severely near or after the Feast of St. Francis, October 4.
Coromell	A night land breeze prevailing from November to May at La Paz, near the southern extremity of the Gulf of California.
Doctor	1. A cooling sea breeze in the Tropics. 2. See HARMATTAN. 3. The strong SE wind which blows on the south African coast. Usually called CAPE DOCTOR.
Elephanta	A strong southerly or southeasterly wind which blows on the Malabar coast of India during the months of September and October and marks the end of the southwest monsoon.
Etesian	A refreshing northerly summer wind of the Mediterranean, especially over the Aegean Sea.
Gregale	A strong northeast wind of the central Mediterranean.
Harmattan	The dry, dusty trade wind blowing off the Sahara Desert across the Gulf of Guinea and the Cape Verde Islands. Sometimes called the DOCTOR, because of its supposed healthful properties.
Knik Wind	A strong southeast wind in the vicinity of Palmer, Alaska, most frequent in the winter.
Kona Storm	A storm over the Hawaiian Islands, characterized by strong southerly or southwesterly winds and heavy rains.
Leste	A hot, dry, easterly wind of the Madeira and Canary Islands.
Levanter	A strong easterly wind of the Mediterranean, especially in the Strait of Gibraltar, attended by cloudy, foggy, and sometimes rainy weather especially in winter.
Levantera	A persistent east wind of the Adriatic, usually accompanied by cloudy weather.
Levanto	A hot southeasterly wind which blows over the Canary Islands.
Leveche	A warm wind in Spain, either a foehn or a hot southerly wind in advance of a low pressure area moving from the Sahara Desert. Called a SIROCCO in other parts of the Mediterranean area.
Maestro	A northwesterly wind with fine weather which blows, especially in summer, in the Adriatic. It is most frequent on the western shore. This wind is also found on the coasts of Corsica and Sardinia.
Matanuska Wind	A strong, gusty, northeast wind which occasionally occurs during the winter in the vicinity of Palmer, Alaska.
Mistral	A cold, dry wind blowing from the north over the northwest coast of the Mediterranean Sea, particularly over the Gulf of Lions. Also called CIERZO. See also FALL WIND.
Nashi, N'aschi	A northeast wind which occurs in winter on the Iranian coast of the Persian Gulf, especially near the entrance to the gulf, and also on the Makran coast. It is probably associated with an outflow from the central Asiatic anticyclone which extends over the high land of Iran. It is similar in character but less severe than the BORA.
Norte	A strong cold northeasterly wind which blows in Mexico and on the shores of the Gulf of Mexico. It results from an outbreak of cold air from the north. It is the Mexican extension of a norther.
Papagayo	A violent northeasterly fall wind on the Pacific coast of Nicaragua and Guatemala. It consists of the cold air mass of a *norte* which has overridden the mountains of Central America. See also TEHUANTEPECER.
Santa Ana	A strong, hot, dry wind blowing out into San Pedro Channel from the southern California desert through Santa Ana Pass.
Shamal	A summer northwesterly wind blowing over Iraq and the Persian Gulf, often strong during the day, but decreasing at night.

Sharki	A southeasterly wind which sometimes blows in the Persian Gulf.
Sirocco	A warm wind of the Mediterranean area, either a foehn or a hot southerly wind in advance of a low pressure area moving from the Sahara or Arabian deserts. Called LEVECHE in Spain.
Squamish	A strong and often violent wind occurring in many of the fjords of British Columbia. Squamishes occur in those fjords oriented in a northeast-southwest or east-west direction where cold polar air can be funneled westward. They are notable in Jervis, Toba, and Bute inlets and in Dean Channel and Portland Canal. Squamishes lose their strength when free of the confining fjords and are not noticeable 15 to 20 miles offshore.
Suestado	A storm with southeast gales, caused by intense cyclonic activity off the coasts of Argentina and Uruguay, which affects the southern part of the coast of Brazil in the winter.
Sumatra	A squall with violent thunder, lightning, and rain, which blows at night in the Malacca Straits, especially during the southwest monsoon. It is intensified by strong mountain breezes.
Taku Wind	A strong, gusty, east-northeast wind, occurring in the vicinity of Juneau, Alaska, between October and March. At the mouth of the Taku River, after which it is named, it sometimes attains hurricane force.
Tehuantepecer	A violent squally wind from north or north-northeast in the Gulf of Tehuantepec (south of southern Mexico) in winter. It originates in the Gulf of Mexico as a norther which crosses the isthmus and blows through the gap between the Mexican and Guatamalan mountains. It may be felt up to 100 miles out to sea. See also PAPAGAYO.
Tramontana	A northeasterly or northerly winter wind off the west coast of Italy. It is a fresh wind of the fine weather mistral type.
Vardar	A cold fall wind blowing from the northwest down the Vardar valley in Greece to the Gulf of Salonica. It occurs when atmospheric pressure over eastern Europe is higher than over the Aegean Sea, as is often the case in winter. Also called VARDARAC.
Warm Braw	A foehn wind in the Schouten Islands north of New Guinea.
White Squall	A sudden, strong gust of wind coming up without warning, noted by whitecaps or white, broken water; usually seen in whirlwind form in clear weather in the tropics.
Williwaw	A sudden blast of wind descending from a mountainous coast to the sea, in the Strait of Magellan or the Aleutian Islands.

AIR MASSES

3509. Types Of Air Masses

Because of large differences in physical characteristics of the earth's surface, particularly the oceanic and continental contrasts, the air overlying these surfaces acquires differing values of temperature and moisture. The processes of radiation and convection in the lower portions of the troposphere act in differing characteristic manners for a number of well-defined regions of the earth. The air overlying these regions acquires characteristics common to the particular area, but contrasting to those of other areas. Each distinctive part of the atmosphere, within which common characteristics prevail over a reasonably large area, is called an **air mass**.

Air masses are named according to their source regions. Four regions are generally recognized: (1) equatorial (E), the doldrums area between the north and south trades; (2) tropical (T), the trade wind and lower temperate regions; (3) polar (P), the higher temperate latitudes; and (4) Arctic or Antarctic (A), the north or south polar regions of ice and snow. This classification is a general indication of relative temperature, as well as latitude of origin.

Air masses are further classified as maritime (m) or continental (c), depending upon whether they form over water or land. This classification is an indication of the relative moisture content of the air mass. Tropical air might be designated maritime tropical (mT) or continental tropical (cT). Similarly, polar air may be either maritime polar (mP) or continental polar (cP). Arctic/Antarctic air, due to the predominance of landmasses and ice fields in the high latitudes, is rarely maritime Arctic (mA). Equatorial air is found exclusively over the ocean surface and is designated neither (cE) nor (mE), but simply (E).

A third classification sometimes applied to tropical and polar air masses indicates whether the air mass is warm (w) or cold (k) relative to the underlying surface. Thus, the symbol mTw indicates maritime tropical air which is warmer than the underlying surface, and cPk indicates continental polar air which is colder than the underlying surface. The w and k classifications are primarily indications of stability

(i.e., change of temperature with increasing height). If the air is cold relative to the surface, the lower portion of the air mass will be heated, resulting in instability (temperature markedly decreases with increasing height) as the warmer air tends to rise by convection. Conversely, if the air is warm relative to the surface, the lower portion of the air mass is cooled, tending to remain close to the surface. This is a stable condition (temperature increases with increasing height).

Two other types of air masses are sometimes recognized. These are monsoon (M), a transitional form between cP and E; and superior (S), a special type formed in the free atmosphere by the sinking and consequent warming of air aloft.

3510. Fronts

As air masses move within the general circulation, they travel from their source regions to other areas dominated by air having different characteristics. This leads to a zone of separation between the two air masses, called a **frontal zone** or **front**, across which temperature, humidity, and wind speed and direction change rapidly. Fronts are represented on weather maps by lines; a cold front is shown with pointed barbs, a warm front with rounded barbs, and an occluded front with both, alternating. A stationary front is shown with pointed and rounded barbs alternating and on opposite sides of the line with the pointed barbs away from the colder air.The front may take on a wave-like character,becoming a "frontal wave."

Before the formation of frontal waves, the isobars (lines of equal atmospheric pressure) tend to run parallel to the fronts. As a wave is formed, the pattern is distorted somewhat, as shown in Figure 3510a. In this illustration, colder air is north of warmer air. In Figures 3510a–3510d isobars are drawn at 4-millibar intervals.

The wave tends to travel in the direction of the general circulation, which in the temperate latitudes is usually in an easterly and slightly poleward direction.

Along the leading edge of the wave, warmer air is replacing colder air. This is called the **warm front**. The trailing edge is the **cold front**, where colder air is underrunning and displacing warmer air.

The warm air, being less dense, tends to ride up greatly over the colder air it is replacing. Partly because of the replacement of cold, dense air with warm, light air, the pressure decreases. Since the slope is gentle, the upper part of a warm frontal surface may be many hundreds of miles ahead of the surface portion. The decreasing pressure, indicated by a "falling barometer," is often an indication of the approach of such a wave. In a slow-moving, well-developed wave, the barometer may begin to fall several days before the wave arrives. Thus, the amount and nature of the change of atmospheric pressure between observations, called pressure tendency, is of assistance in predicting the approach of such a system.

The advancing cold air, being more dense, tends to ride under the warmer air at the cold front, lifting it to greater heights. The slope here is such that the upper-air portion of the cold front is behind the surface position relative to its motion. After a cold front has passed, the pressure increases, giving a rising barometer.

In the first stages, these effects are not marked, but as the wave continues to grow, they become more pronounced, as shown in Figure 3510b. As the amplitude of the wave increases, pressure near the center usually decreases, and the low is said to "deepen." As it deepens, its forward speed generally decreases.

The approach of a well-developed warm front (i.e., when the warm air is mT) is usually heralded not only by falling pressure, but also by a more-or-less regular sequence of clouds. First, cirrus appear. These give way successively to cirrostratus, altostratus, altocumulus, and nimbostratus. Brief showers may precede the steady rain accompanying the nimbostratus.

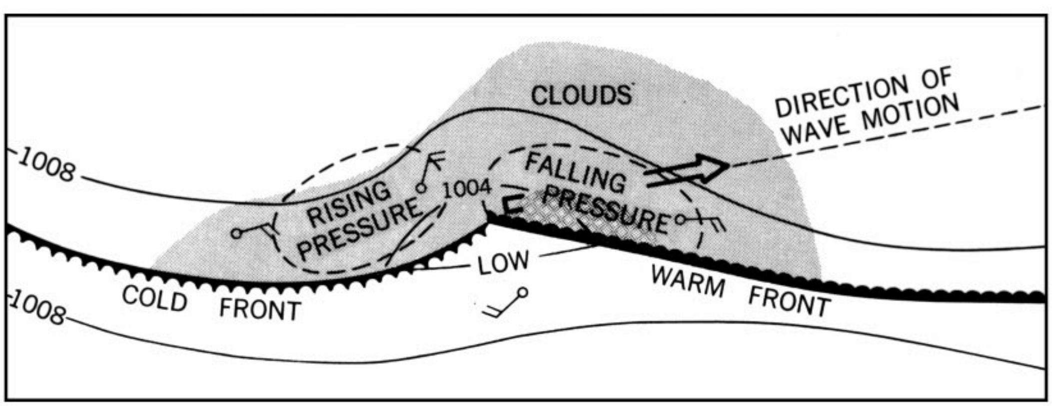


Figure 3510a. First stage in the development of a frontal wave (top view).

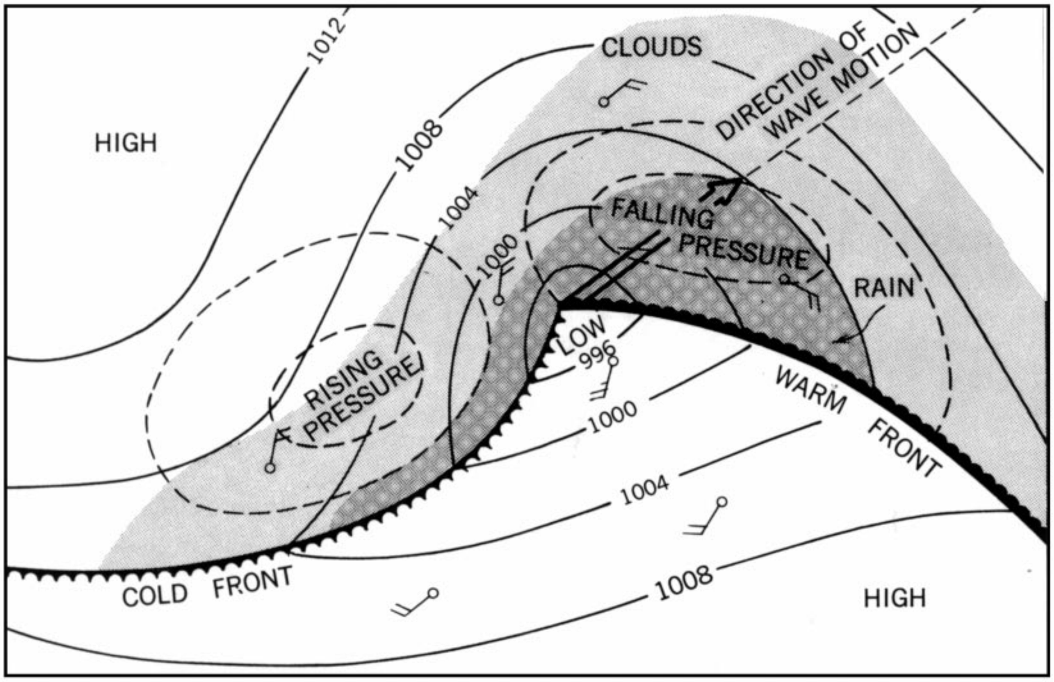


Figure 3510b. A fully developed frontal wave (top view).

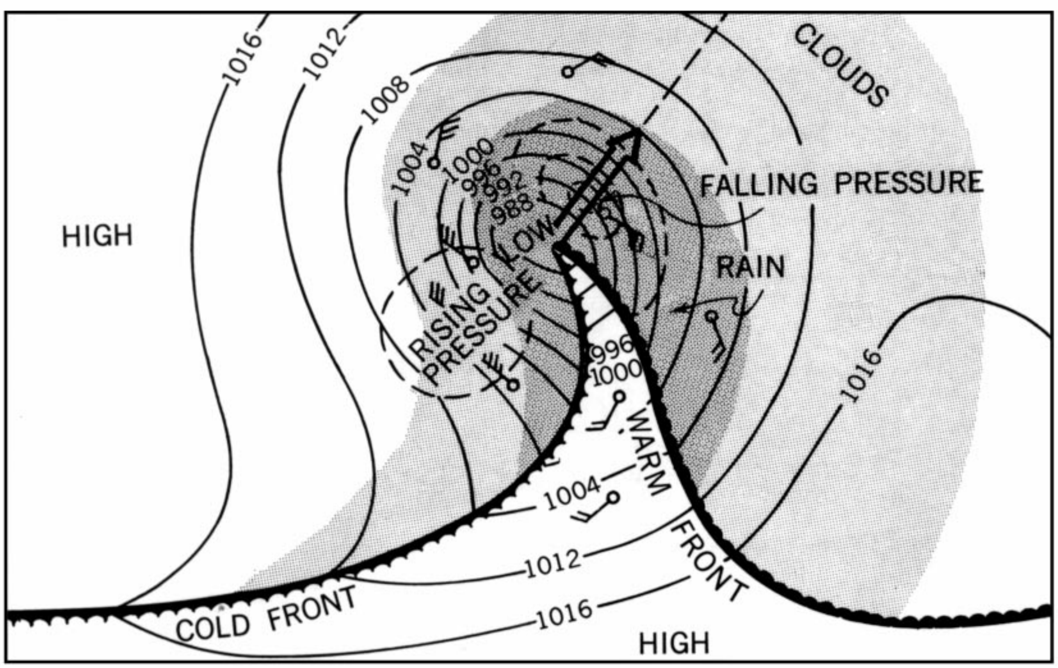


Figure 3510c. A frontal wave nearing occlusion (top view).

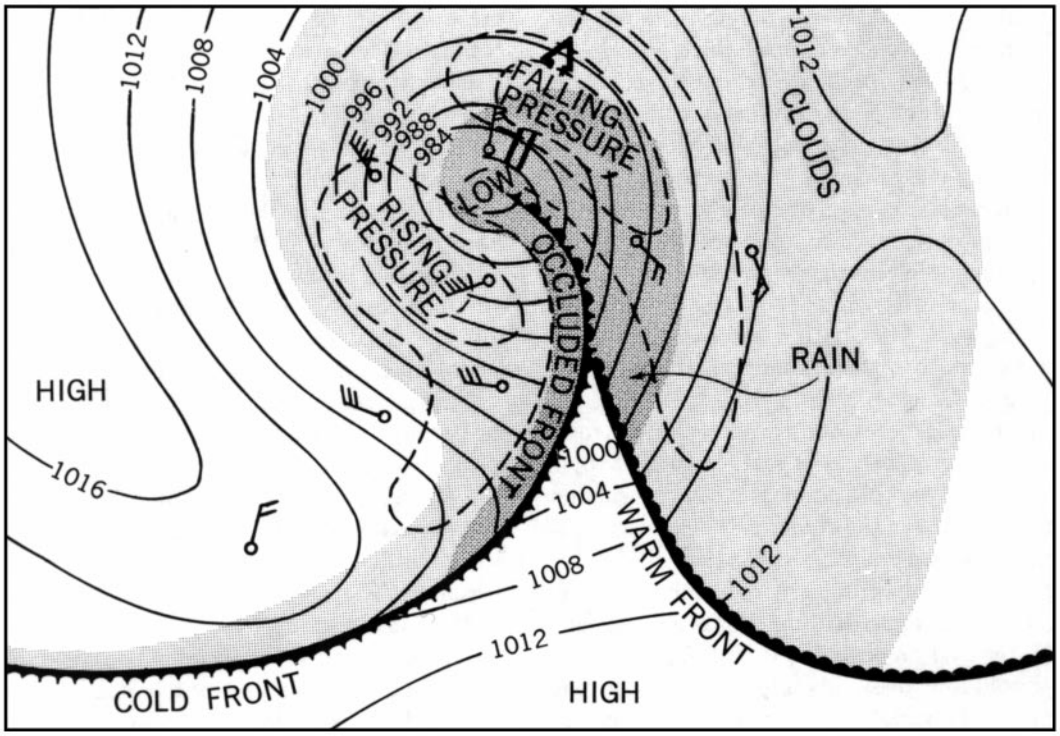


Figure 3510d. An occluded front (top view).

As the warm front passes, the temperature rises, the wind shifts clockwise (in the Northern Hemisphere), and the steady rain stops. Drizzle may fall from low-lying stratus clouds, or there may be fog for some time after the wind shift. During passage of the warm sector between the warm front and the cold front, there is little change in temperature or pressure. However, if the wave is still growing and the low deepening, the pressure might slowly decrease. In the warm sector the skies are generally clear or partly cloudy, with cumulus or stratocumulus clouds most frequent. The warm air is usually moist, and haze or fog may often be present.

As the faster moving, steeper cold front passes, the wind veers (shifts clockwise in the Northern Hemisphere counterclockwise in the Southern Hemisphere), the temperature falls rapidly, and there are often brief and sometimes violent squalls with showers, frequently accompanied by thunder and lightning. Clouds are usually of the convective type. A cold front usually coincides with a well-defined wind-shift line (a line along which the wind shifts abruptly from southerly or southwesterly to northerly or northwesterly in the Northern Hemisphere, and from northerly or northwesterly to southerly or southwesterly in the Southern Hemisphere). At sea a series of brief showers accompanied by strong, shifting winds may occur along or some distance (up to 200 miles) ahead of a cold front. These are called **squalls** (in common nautical use, the term squall may be additionally

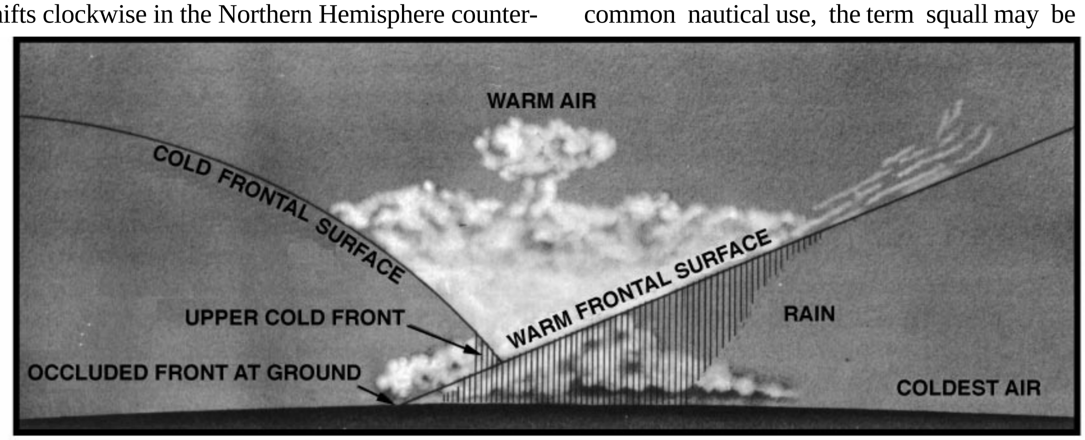


Figure 3510e. An occluded front (cross section).

applied to any severe local storm accompanied by gusty winds, precipitation, thunder, and lightning), and the line along which they occur is called a **squall line**.

Because of its greater speed and steeper slope, which may approach or even exceed the vertical near the earth's surface (due to friction), a cold front and its associated weather pass more quickly than a warm front. After a cold front passes, the pressure rises, often quite rapidly, the visibility usually improves, and the clouds tend to diminish. Clear, cool or cold air replaces the warm hazy air.

As the wave progresses and the cold front approaches the slower moving warm front, the low becomes deeper and the warm sector becomes smaller, as shown in Figure 3510c.

Finally, the faster moving cold front overtakes the warm front (Figure 3510d), resulting in an **occluded front** at the surface, and an upper front aloft (Figure 3510e). When the two parts of the cold air mass meet, the warmer portion tends to rise above the colder part. The warm air continues to rise until the entire frontal system dissipates. As the warmer air is replaced by colder air, the pressure gradually rises, a process called **filling**. This usually occurs within a few days after an occluded front forms. Finally, there results a cold low, or simply a low pressure system across which little or no gradient in temperature and moisture can be found.

The sequence of weather associated with a low depends greatly upon the observer's location with respect to the path of the center. That described above assumes that the low center passes poleward of the observer. If the low center passes south of the observer, between the observer and the equator, the abrupt weather changes associated with the passage of fronts are not experienced. Instead, the change from the weather characteristically found ahead of a warm front, to that behind a cold front, takes place gradually, the exact sequence dictated by distance from the center, and the severity and age of the low.

Although each low generally follows this pattern, no two are ever exactly alike. Other centers of low pressure and high pressure, and the air masses associated with them, even though they may be 1,000 miles or more away, influence the formation and motion of individual low centers and their accompanying weather. Particularly, a high stalls or diverts a low. This is true of temporary highs as well as semi-permanent highs, but not to as great a degree.

3511. Cyclones And Anticyclones

An area of relatively low pressure, generally circular, is called a **cyclone**. Its counterpart for high pressure is called an **anticyclone**. These terms are used particularly in connection with the winds associated with such centers. Wind tends to blow from an area of high pressure to one of low pressure, but due to rotation of the earth, wind is deflected toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere.

Because of the rotation of the earth, therefore, the circulation tends to be counterclockwise around areas of low pressure and clockwise around areas of high pressure in the Northern Hemisphere, and the speed is proportional to the spacing of isobars. In the Southern Hemisphere, the direction of circulation is reversed. Based upon this condition, a general rule, known as Buys Ballot's Law, or the Baric Wind Law, can be stated:

If an observer in the Northern Hemisphere faces away from the surface wind, the low pressure is toward his left; the high pressure is toward his right.

If an observer in the Southern Hemisphere faces away from the surface wind, the low pressure is toward his right; the high pressure is toward his left.

In a general way, these relationships apply in the case of the general distribution of pressure, as well as to temporary local pressure systems.

The reason for the wind shift along a front is that the isobars have an abrupt change of direction along these lines. Since the direction of the wind is directly related to the direction of isobars, any change in the latter results in a shift in the wind direction.

In the Northern Hemisphere, the wind shifts toward the right (clockwise) when either a warm or cold front passes. In the Southern Hemisphere, the shift is toward the left (counterclockwise). When an observer is on the poleward side of the path of a frontal wave, wind shifts are reversed (i.e., to the left in the Northern Hemisphere and to the right in the Southern Hemisphere).

In an anticyclone, successive isobars are relatively far apart, resulting in light winds. In a cyclone, the isobars are more closely spaced. With a steeper pressure gradient, the winds are stronger.

Since an anticyclonic area is a region of outflowing winds, air is drawn into it from aloft. Descending air is warmed, and as air becomes warmer, its capacity for holding uncondensed moisture increases. Therefore, clouds tend to dissipate. Clear skies are characteristic of an anticyclone, although scattered clouds and showers are sometimes encountered.

In contrast, a cyclonic area is one of converging winds. The resulting upward movement of air results in cooling, a condition favorable to the formation of clouds and precipitation. More or less continuous rain and generally stormy weather are usually associated with a cyclone.

Between the two hemispheric belts of high pressure associated with the horse latitudes, called subtropical anticyclones, cyclones form only occasionally over certain areas at sea, generally in summer and fall. Tropical cyclones (hurricanes and typhoons) are usually quite violent.

In the areas of the prevailing westerlies in temperate latitudes, migratory cyclones (lows) and anticyclones (highs) are a common occurrence. These are sometimes called extratropical cyclones and extratropical anticyclones to distinguish them from the more violent tropical cyclones. Formation occurs over sea and land. The lows intensify as they move poleward; the highs weaken as they move equatorward. In their early stages, cyclones are elongated, as shown in Figure 3510a, but as their life cycle proceeds, they become more nearly circular (Figure 3510b, Figure 3510c, and Figure 3510d).

LOCAL WEATHER PHENOMENA

3512. Local Winds

In addition to the winds of the general circulation and those associated with migratory cyclones and anticyclones, there are numerous local winds which influence the weather in various places.

The most common are the land and sea breezes, caused by alternate heating and cooling of land adjacent to water. The effect is similar to that which causes the monsoons, but on a much smaller scale, and over shorter periods. By day the land is warmer than the water, and by night it is cooler. This effect occurs along many coasts during the summer. Between about 0900 and 1100 local time the temperature of the land becomes greater than that of the adjacent water. The lower levels of air over the land are warmed, and the air rises, drawing in cooler air from the sea. This is the **sea breeze**. Late in the afternoon, when the sun is low in the sky, the temperature of the two surfaces equalizes and the breeze stops. After sunset, as the land cools below the sea temperature, the air above it is also cooled. The contracting cool air becomes more dense, increasing the pressure near the surface. This results in an outflow of winds to the sea. This is the **land breeze**, which blows during the night and dies away near sunrise. Since the atmospheric pressure changes associated with this cycle are not great, the accompanying winds generally do not exceed gentle to moderate breezes. The circulation is usually of limited extent, reaching a distance of perhaps 20 miles inland, and not more than 5 or 6 miles offshore, and to a height of a few hundred feet. In the doldrums and subtropics, this process is repeated with great regularity throughout most of the year. As the latitude increases, it becomes less prominent, being masked by winds of migratory cyclones and anticyclones. However, the effect often may be present to reinforce, retard, or deflect stronger prevailing winds.

Varying conditions of topography produce a large variety of local winds throughout the world. Winds tend to follow valleys, and to be deflected from high banks and shores. In mountain areas wind flows in response to temperature distribution and gravity. An **anabolic wind** is one that blows up an incline, usually as a result of surface heating. A **katabatic wind** is one which blows down an incline. There are two types, foehn and fall wind.

The foehn (fãn) is a warm dry wind which initiates from horizontally moving air encountering a mountain barrier. As it blows upward to clear the mountains, it is cooled below the dew point, resulting in clouds and rain on the windward side. As the air continues to rise, its rate of cooling is reduced because the condensing water vapor gives off heat to the surrounding atmosphere. After crossing the mountain barrier, the air flows downward along the leeward slope, being warmed by compression as it descends to lower levels. Since it loses less heat on the ascent than it gains during descent, and since it has lost its moisture during ascent, it arrives at the bottom of the mountains as very warm, dry air. This accounts for the warm, arid regions along the eastern side of the Rocky Mountains and in similar areas. In the Rocky Mountain region this wind is known by the name **chinook**. It may occur at any season of the year, at any hour of the day or night, and have any speed from a gentle breeze to a gale. It may last for several days, or for a very short period. Its effect is most marked in winter, when it may cause the temperature to rise as much as 20°F to 30°F within 15 minutes, and cause snow and ice to melt within a few hours. On the west coast of the United States, a foehn wind, given the name **Santa Ana**, blows through a pass and down a valley of that name in Southern California. This wind is frequently very strong and may endanger small craft immediately off the coast.

A cold wind blowing down an incline is called a **fall wind**. Although it is warmed somewhat during descent, as is the foehn, it remains cold relative to the surrounding air. It occurs when cold air is dammed up in great quantity on the windward side of a mountain and then spills over suddenly, usually as an overwhelming surge down the other side. It is usually quite violent, sometimes reaching hurricane force. A different name for this type wind is given at each place where it is common. The **tehuantepecer** of the Mexican and Central American coast, the **pampero** of the Argentine coast, the **mistral** of the western Mediterranean, and the **bora** of the eastern Mediterranean are examples of this wind.

Many other local winds common to certain areas have been given distinctive names.

A **blizzard** is a violent, intensely cold wind laden with snow mostly or entirely picked up from the ground, although the term is often used popularly to refer to any heavy snowfall accompanied by strong wind. A **dust whirl** is a rotating column of air about 100 to 300 feet in height, carrying dust, leaves, and other light material. This wind, which is similar to a waterspout at sea, is given various local names such as dust devil in southwestern United States and desert devil in South Africa. A **gust** is a sudden, brief increase in wind speed, followed by a slackening, or the violent wind or squall that accompanies a thunderstorm. A puff of wind or a light breeze affecting a small area, such as would cause patches of ripples on the surface of water, is called a **cat's paw**.

3513. Waterspouts

A **waterspout** is a small, whirling storm over ocean or inland waters. Its chief characteristic is a funnel-shaped cloud; when fully developed it extends from the surface of the water to the base of a cumulus cloud. The water in a waterspout is mostly confined to its lower portion, and may

Figure 3513. Waterspouts.

be either salt spray drawn up by the sea surface, or freshwater resulting from condensation due to the lowered pressure in the center of the vortex creating the spout. The air in waterspouts may rotate clockwise or counterclockwise, depending on the manner of formation. They are found most frequently in tropical regions, but are not uncommon in higher latitudes.

There are two types of waterspouts: those derived from violent convective storms over land moving seaward, called tornadoes, and those formed over the sea and which are associated with fair or foul weather. The latter type is most common, lasts a maximum of 1 hour, and has variable strength. Many waterspouts are no stronger than dust whirlwinds, which they resemble; at other times they are strong enough to destroy small craft or to cause damage to larger vessels, although modern ocean-going vessels have little to fear.

Waterspouts vary in diameter from a few feet to several hundred feet, and in height from a few hundred feet to several thousand feet. Sometimes they assume fantastic shapes; in early stages of development an hour glass shape between cloud and sea is common. Since a waterspout is often inclined to the vertical, its actual length may be much greater than indicated by its height.

3514. Deck Ice

Ships traveling through regions where the air temperature is below freezing may acquire thick deposits of ice as a result of salt spray freezing on the rigging, deckhouses, and deck areas. This accumulation of ice is called **ice accretion**. Also, precipitation may freeze to the superstructure and exposed areas of the vessel, increasing the load of ice.

On small vessels in heavy seas and freezing weather, deck ice may accumulate very rapidly and increase the topside weight enough to capsize the vessel. Fishing vessels with outriggers, A-frames, and other top hamper are particularly susceptible.

Figure 3514. Deck ice.

RESTRICTED VISIBILITY

3515. Fog

Fog is a cloud whose base is at the surface of the earth. Fog is composed of droplets of water or ice crystals (ice fog) formed by condensation or crystallization of water vapor in the air.

Radiation fog forms over low-lying land on clear, calm nights. As the land radiates heat and becomes cooler, it cools the air immediately above the surface. This causes a temperature inversion to form, the temperature increasing with height. If the air is cooled to its dew point, fog forms. Often, cooler and more dense air drains down surrounding slopes to heighten the effect. Radiation fog is often quite shallow, and is usually densest at the surface. After sunrise the fog may “lift” and gradually dissipate, usually being entirely gone by noon. At sea the temperature of the water undergoes little change between day and night, and so radiation fog is seldom encountered more than 10 miles from shore.

Advection fog forms when warm, moist air blows over a colder surface and is cooled below its dew point. It is most commonly encountered at sea, may be quite dense, and often persists over relatively long periods. Advection fog is common over cold ocean currents. If the wind is strong enough to thoroughly mix the air, condensation may take place at some distance above the surface of the earth, forming low stratus clouds rather than fog.

Off the coast of California, seasonal winds create an offshore current which displaces the warm surface water, causing an upwelling of colder water. Moist Pacific air is transported along the coast in the same wind system, and is cooled by the relatively cold water. Advection fog results. In the coastal valleys, fog is sometimes formed when moist air blown inland during the afternoon is cooled by radiation during the night.

When very cold air moves over warmer water, wisps of visible water vapor may rise from the surface as the water

"steams," In extreme cases this **frost smoke**, or **Arctic sea smoke**, may rise to a height of several hundred feet, the portion near the surface constituting a dense fog which obscures the horizon and surface objects, but usually leaves the sky relatively clear.

Haze consists of fine dust or salt particles in the air, too small to be individually apparent, but in sufficient number to reduce horizontal visibility and cast a bluish or yellowish veil over the landscape, subduing its colors and making objects appear indistinct. This is sometimes called **dry haze** to distinguish it from **damp haze**, which consists of small water droplets or moist particles in the air, smaller and more scattered than light fog. In international meteorological practice, the term "haze" is used to refer to a condition of atmospheric obscurity caused by dust and smoke.

Mist is synonymous with drizzle in the United States but is often considered as intermediate between haze and fog in its properties. Heavy mist can reduce visibility to a mile or less.

A mixture of smoke and fog is called **smog**. Normally it is not a problem in navigation except in severe cases accompanied by an offshore wind from the source, when it may reduce visibility to 2–4 miles.

ATMOSPHERIC EFFECTS ON LIGHT RAYS

3516. Mirage

Light is refracted as it passes through the atmosphere. When refraction is normal, objects appear slightly elevated, and the visible horizon is farther from the observer than it otherwise would be. Since the effects are uniformly progressive, they are not apparent to the observer. When refraction is not normal, some form of mirage may occur. A **mirage** is an optical phenomenon in which objects appear distorted, displaced (raised or lowered), magnified, multiplied, or inverted due to varying atmospheric refraction which occurs when a layer of air near the earth's surface differs greatly in density from surrounding air. This may occur when there is a rapid and sometimes irregular change of temperature or humidity with height.

If there is a temperature inversion (increase of temperature with height), particularly if accompanied by a rapid decrease in humidity, the refraction is greater than normal. Objects appear elevated, and the visible horizon is farther away. Objects which are normally below the horizon become visible. This is called **looming**. If the upper portion of an object is raised much more than the bottom part, the object appears taller than usual, an effect called **towering**. If the lower part of an object is raised more than the upper part, the object appears shorter, an effect called **stooping**. When the refraction is greater than normal, a **superior mirage** may occur. An inverted image is seen above the object, and sometimes an erect image appears over the inverted one, with the bases of the two images touching. Greater than normal refraction usually occurs when the water is much colder than the air above it.

If the temperature decrease with height is much greater than normal, refraction is less than normal, or may even cause bending in the opposite direction. Objects appear lower than normal, and the visible horizon is closer to the observer. This is called **sinking**. Towering or stooping may occur if conditions are suitable. When the refraction is reversed, an **inferior mirage** may occur. A ship or an island appears to be floating in the air above a shimmering horizon, possibly with an inverted image beneath it. Conditions suitable to the formation of an inferior mirage occur when the surface is much warmer than the air above it. This usually requires a heated landmass, and therefore is more common near the coast than at sea.

When refraction is not uniformly progressive, objects may appear distorted, taking an almost endless variety of shapes. The sun when near the horizon is one of the objects most noticeably affected. A **fata morgana** is a complex mirage characterized by marked distortion, generally in the vertical. It may cause objects to appear towering, magnified, and at times even multiplied.

3517. Sky Coloring

White light is composed of light of all colors. Color is related to wavelength, the visible spectrum varying from about 0.000038 to 0.000076 centimeters. The characteristics of each color are related to its wavelength (or frequency). The shorter the wavelength, the greater the amount of bending when light is refracted. It is this principle that permits the separation of light from celestial bodies into a **spectrum** ranging from red, through orange, yellow, green, and blue, to violet, with long-wave **infrared** being slightly outside the visible range at one end and short-wave **ultraviolet** being slightly outside the visible range at the other end. Light of shorter wavelength is scattered and diffracted more than that of longer wavelength.

Light from the sun and moon is white, containing all colors. As it enters the earth's atmosphere, a certain amount of it is scattered. The blue and violet, being of shorter wavelength than other colors, are scattered most. Most of the violet light is absorbed in the atmosphere. Thus, the scattered blue light is most apparent, and the sky appears blue. At great heights, above most of the atmosphere, it appears black.

When the sun is near the horizon, its light passes through more of the atmosphere than when higher in the sky, resulting in greater scattering and absorption of blue and green light, so that a larger percentage of the red and orange light penetrates to the observer. For this reason the sun and moon appear redder at this time, and when this light

falls upon clouds, they appear colored. This accounts for the colors at sunset and sunrise. As the setting sun approaches the horizon, the sunset colors first appear as faint tints of yellow and orange. As the sun continues to set, the colors deepen. Contrasts occur, due principally to difference in height of clouds. As the sun sets, the clouds become a deeper red, first the lower clouds and then the higher ones, and finally they fade to a gray.

When there is a large quantity of smoke, dust, or other material in the sky, unusual effects may be observed. If the material in the atmosphere is of suitable substance and quantity to absorb the longer wave red, orange, and yellow radiation, the sky may have a greenish tint, and even the sun or moon may appear green. If the green light, too, is absorbed, the sun or moon may appear blue. A green moon or blue moon is most likely to occur when the sun is slightly below the horizon and the longer wavelength light from the sun is absorbed, resulting in green or blue light being cast upon the atmosphere in front of the moon. The effect is most apparent if the moon is on the same side of the sky as the sun.

3518. Rainbows

The **rainbow**, that familiar arc of concentric colored bands seen when the sun shines on rain, mist, spray, etc., is caused by refraction, internal reflection, and diffraction of sunlight by the drops of water. The center of the arc is a point 180° from the sun, in the direction of a line from the sun, through the observer. The radius of the brightest rainbow is 42°. The colors are visible because of the difference in the amount of refraction of the different colors making up white light, the light being spread out to form a spectrum. Red is on the outer side and blue and violet on the inner side, with orange, yellow, and green between, in that order from red.

Sometimes a secondary rainbow is seen outside the primary one, at a radius of about 50°. The order of colors of this rainbow is reversed. On rare occasions a faint rainbow is seen on the same side as the sun. The radius of this rainbow and the order of colors are the same as those of the primary rainbow.

A similar arc formed by light from the moon (a lunar rainbow) is called a **moonbow**. The colors are usually very faint. A faint, white arc of about 39° radius is occasionally seen in fog opposite the sun. This is called a **fogbow**, although its origin is controversial, some considering it a halo.

3519. Halos

Refraction, or a combination of refraction and reflection, of light by ice crystals in the atmosphere may cause a **halo** to appear. The most common form is a ring of light of radius 22° or 46° with the sun or moon at the center. Cirrostratus clouds are a common source of atmospheric ice crystals. Occasionally a faint, white circle with a radius of 90° appears around the sun. This is called a **Hevelian halo**. It is probably caused by refraction and internal reflection of the sun's light by bipyramidal ice crystals. A halo formed by refraction is usually faintly colored like a rainbow, with red nearest the celestial body, and blue farthest from it.

A brilliant rainbow-colored arc of about a quarter of a circle with its center at the zenith, and the bottom of the arc about 46° above the sun, is called a **circumzenithal arc**. Red is on the outside of the arc, nearest the sun. It is produced by the refraction and dispersion of the sun's light striking the top of prismatic ice crystals in the atmosphere. It usually lasts for only about 5 minutes, but may be so brilliant as to be mistaken for an unusually bright rainbow. A similar arc formed 46° below the sun, with red on the upper side, is called a **circumhorizontal arc**. Any arc tangent to a heliocentric halo (one surrounding the sun) is called a **tangent arc**. As the sun increases in elevation, such arcs tangent to the halo of 22° gradually bend their ends toward each other. If they meet, the elongated curve enclosing the circular halo is called a **circumscribed halo**. The inner edge is red.

A halo consisting of a faint, white circle through the sun and parallel to the horizon is called a **parhelic circle**. A similar one through the moon is called a **paraselenic circle**. They are produced by reflection of sunlight or moonlight from vertical faces of ice crystals.

A **parhelion (plural: parhelia)** is a form of halo consisting of an image of the sun at the same altitude and some distance from it, usually 22°, but occasionally 46°. A similar phenomenon occurring at an angular distance of 120° (sometimes 90° or 140°) from the sun is called a **paranthelion**. One at an angular distance of 180°, a rare occurrence, is called an **anthelion**, although this term is also used to refer to a luminous, colored ring or glory sometimes seen around the shadow of one's head on a cloud or fog bank. A parhelion is popularly called a **mock sun** or **sun dog**. Similar phenomena in relation to the moon are called **paraselene** (popularly a **mock moon** or **moon dog**), **parantiselene**, and **antiselene**. The term parhelion should not be confused with perihelion, the orbital point nearest the sun when the sun is the center of attraction.

A **sun pillar** is a glittering shaft of white or reddish light occasionally seen extending above and below the sun, usually when the sun is near the horizon. A phenomenon similar to a sun pillar, but observed in connection with the moon, is called a **moon pillar**. A rare form of halo in which horizontal and vertical shafts of light intersect at the sun is called a **sun cross**. It is probably due to the simultaneous occurrence of a sun pillar and a parhelic circle.

3520. Corona

When the sun or moon is seen through altostratus clouds, its outline is indistinct, and it appears surrounded by a glow of light called a **corona**. This is somewhat similar in appearance to the corona seen around the sun during a solar eclipse. When the effect is due to clouds, however, the glow may be accompanied by one or more rainbow-colored rings

of small radii, with the celestial body at the center. These can be distinguished from a halo by their much smaller radii and also by the fact that the order of the colors is reversed, red being on the inside, nearest the body, in the case of the halo, and on the outside, away from the body, in the case of the corona.

A corona is caused by diffraction of light by tiny droplets of water. The radius of a corona is inversely proportional to the size of the water droplets. A large corona indicates small droplets. If a corona decreases in size, the water droplets are becoming larger and the air more humid. This may be an indication of an approaching rainstorm. The glow portion of a corona is called an **aureole**.

3521. The Green Flash

As light from the sun passes through the atmosphere, it is refracted. Since the amount of bending is slightly different for each color, separate images of the sun are formed in each color of the spectrum. The effect is similar to that of imperfect color printing, in which the various colors are slightly out of register. However, the difference is so slight that the effect is not usually noticeable. At the horizon, where refraction is maximum, the greatest difference, which occurs between violet at one end of the spectrum and red at the other, is about 10 seconds of arc. At latitudes of the United States, about 0.7 second of time is needed for the sun to change altitude by this amount when it is near the horizon. The red image, being bent least by refraction, is first to set and last to rise. The shorter wave blue and violet colors are scattered most by the atmosphere, giving it its characteristic blue color. Thus, as the sun sets, the green image may be the last of the colored images to drop out of sight. If the red, orange, and yellow images are below the horizon, and the blue and violet light is scattered and absorbed, the upper rim of the green image is the only part seen, and the sun appears green. This is the **green flash**. The shade of green varies, and occasionally the blue image is seen, either separately or following the green flash (at sunset). On rare occasions the violet image is also seen. These colors may also be seen at sunrise, but in reverse order. They are occasionally seen when the sun disappears behind a cloud or other obstruction.

The phenomenon is not observed at each sunrise or sunset, but under suitable conditions is far more common than generally supposed. Conditions favorable to observation of the green flash are a sharp horizon, clear atmosphere, a temperature inversion, and a very attentive observer. Since these conditions are more frequently met when the horizon is formed by the sea than by land, the phenomenon is more common at sea. With a sharp sea horizon and clear atmosphere, an attentive observer may see the green flash at as many as 50 percent of sunsets and sunrises, although a telescope may be needed for some of the observations.

Duration of the green flash (including the time of blue and violet flashes) of as long as 10 seconds has been reported, but such length is rare. Usually it lasts for a period of about $^1/_2$ to 2 $^1/_2$ seconds, with about 1 $^1/_4$ seconds being average. This variability is probably due primarily to changes in the index of refraction of the air near the horizon.

Under favorable conditions, a momentary green flash has been observed at the setting of Venus and Jupiter. A telescope improves the chances of seeing such a flash from a planet, but is not a necessity.

3522. Crepuscular Rays

Crepuscular rays are beams of light from the sun passing through openings in the clouds, and made visible by illumination of dust in the atmosphere along their paths. Actually, the rays are virtually parallel, but because of perspective, appear to diverge. Those appearing to extend downward are popularly called **backstays of the sun**, or the sun drawing water. Those extending upward and across the sky, appearing to converge toward a point 180° from the sun, are called **anticrepuscular rays**.

THE ATMOSPHERE AND RADIO WAVES

3523. Atmospheric Electricity

Radio waves traveling through the atmosphere exhibit many of the properties of light, being refracted, reflected, diffracted, and scattered. These effects are discussed in greater detail in Chapter 10, Radio Waves in Navigation.

Various conditions induce the formation of electrical charges in the atmosphere. When this occurs, there is often a difference of electron charge between various parts of the atmosphere, and between the atmosphere and earth or terrestrial objects. When this difference exceeds a certain minimum value, depending upon the conditions, the static electricity is discharged, resulting in phenomena such as lightning or St. Elmo’s fire.

Lightning is the discharge of electricity from one part of a thundercloud to another, between different clouds, or between a cloud and the earth or a terrestrial object.

Enormous electrical stresses build up within thunderclouds, and between such clouds and the earth. At some point the resistance of the intervening air is overcome. At first the process is a progressive one, probably starting as a brush discharge (St. Elmo’s fire), and growing by ionization. The breakdown follows an irregular path along the line of least resistance. A hundred or more individual discharges may be necessary to complete the path between points of opposite polarity. When this “leader stroke” reaches its destination, a heavy “main stroke” immediately follows in the opposite direction. This main stroke is the visible lightning, which may

be tinted any color, depending upon the nature of the gases through which it passes. The illumination is due to the high degree of ionization of the air, which causes many of the atoms to become excited and emit radiation.

Thunder, the noise that accompanies lightning, is caused by the heating and ionizing of the air by lightning, which results in rapid expansion of the air along its path and the sending out of a compression wave. Thunder may be heard at a distance of as much as 15 miles, but generally does not carry that far. The elapsed time between the flash of lightning and reception of the accompanying sound of thunder is an indication of the distance, because of the difference in travel time of light and sound. Since the former is comparatively instantaneous, and the speed of sound is about 1,117 feet per second, the approximate distance in nautical miles is equal to the elapsed time in seconds, divided by 5.5. If the thunder accompanying lightning cannot be heard due to its distance, the lightning is called **heat lightning**.

St. Elmo's fire is a luminous discharge of electricity from pointed objects such as the masts and antennas of ships, lightning rods, steeples, mountain tops, blades of grass, human hair, arms, etc., when there is a considerable difference in the electrical charge between the object and the air. It appears most frequently during a storm. An object from which St. Elmo's fire emanates is in danger of being struck by lightning, since this discharge may be the initial phase of the leader stroke. Throughout history those who have not understood St. Elmo's fire have regarded it with superstitious awe, considering it a supernatural manifestation. This view is reflected in the name **corposant** (from "corpo santo," meaning "body of a saint") sometimes given this phenomenon.

The **aurora** is a luminous glow appearing in varied forms in the thin atmosphere high above the earth in high latitudes. It closely follows solar flare activity, and is believed caused by the excitation of atoms of oxygen and hydrogen, and molecules of nitrogen (N_2). Auroras extend across hundreds of kilometers of sky, in colored sheets, folds, and rays, constantly changing in form and color. On occasion they are seen in temperate or even more southern latitudes. The maximum occurrence is at about 64–70° of geomagnetic latitude. These are called the **auroral zones** in both northern and southern regions.

The aurora of the northern regions is the **Aurora Borealis** or **northern lights**, and that of the southern region the **Aurora Australis**, or **southern lights**. The term **polar lights** is occasionally used to refer to either.

In the northern zone, there is an apparent horizontal motion to the westward in the evening and eastward in the morning; a general southward motion occurs during the course of the night.

Variation in auroral activity occurs in sequence with the 11-year sunspot cycle, and also with the 27-day period of the sun's synodical rotation. Daily occurrence is greatest near midnight.

WEATHER ANALYSIS AND FORECASTING

3524. Forecasting Weather

The prediction of weather at some future time is based upon an understanding of weather processes, and observations of present conditions. Thus, when there is a certain sequence of cloud types, rain usually can be expected to follow. If the sky is cloudless, more heat will be received from the sun by day, and more heat will be radiated outward from the warm earth by night than if the sky is overcast. If the wind is from a direction that transports warm, moist air over a colder surface, fog can be expected. A falling barometer indicates the approach of a "low," probably accompanied by stormy weather. Thus, before meteorology passed from an "art" to "science," many individuals learned to interpret certain atmospheric phenomena in terms of future weather, and to make reasonably accurate forecasts for short periods into the future.

With the establishment of weather observation stations, continuous and accurate weather information became available. As observations expanded and communication techniques improved, knowledge of simultaneous conditions over wider areas became available. This made possible the collection of "synoptic" reports at civilian and military forecast centers.

Individual observations are made at stations on shore and aboard vessels at sea. Observations aboard merchant ships at sea are made and transmitted on a voluntary and cooperative basis. The various national meteorological services supply shipmasters with blank forms, printed instructions, and other materials essential to the making, recording, and interpreting of observations. Any shipmaster can render a particularly valuable service by reporting all unusual or non-normal weather occurrences.

Symbols and numbers are used to indicate on a synoptic chart, popularly called a weather map, the conditions at each observation station. Isobars are drawn through lines of equal atmospheric pressure, fronts are located and symbolically marked (See Figure 3525), areas of precipitation and fog are indicated, etc.

Ordinarily, weather maps for surface observations are prepared every 6 (sometimes 3) hours. In addition, synoptic charts for selected heights are prepared every 12 (sometimes 6) hours. Knowledge of conditions aloft is of value in establishing the three-dimensional structure and motion of the atmosphere as input to the forecast.

With the advent of the digital computer, highly sophisticated numerical models have been developed to analyze and forecast weather patterns. The civil and military weath-

er centers prepare and disseminate vast numbers of weather charts (analyses and prognoses) daily to assist local forecasters in their efforts to provide users with accurate weather forecasts. The accuracy of forecast decreases with the length of the forecast period. A 12-hour forecast is likely to be more reliable than a 24-hour forecast. Long term forecasts for 2 weeks or a month in advance are limited to general statements. For example, a prediction may be made about which areas will have temperatures above or below normal, and how precipitation will compare with normal, but no attempt is made to state that rainfall will occur at a certain time and place.

Forecasts are issued for various areas. The national meteorological services of most maritime nations, including the United States, issue forecasts for ocean areas and warnings of approaching storms. The efforts of the various nations are coordinated through the World Meteorological Organization.

3525. Weather Forecast Dissemination

Dissemination of weather information is carried out in a number of ways. Forecasts are widely broadcast by commercial and government radio stations and printed in newspapers. Shipping authorities on land are kept informed by telegraph and telephone. Visual storm warnings are displayed in various ports, and storm warnings are broadcast by radio.

Through the use of codes, a simplified version of synoptic weather charts is transmitted to various stations ashore and afloat. Rapid transmission of completed maps is accomplished by facsimile. This system is based upon detailed scanning, by a photoelectric detector, of illuminated black and white copy. The varying degrees of light intensity are converted to electric energy, which is transmitted to the receiver and converted back to a black and white presentation. The proliferation of both commercial and restricted computer bulletin board systems having weather information has also greatly increased the accessibility of environmental data.

Complete information on dissemination of weather information by radio is provided in *Selected Worldwide Marine Weather Broadcasts*, published jointly by the National Weather Service and the Naval Meteorology and

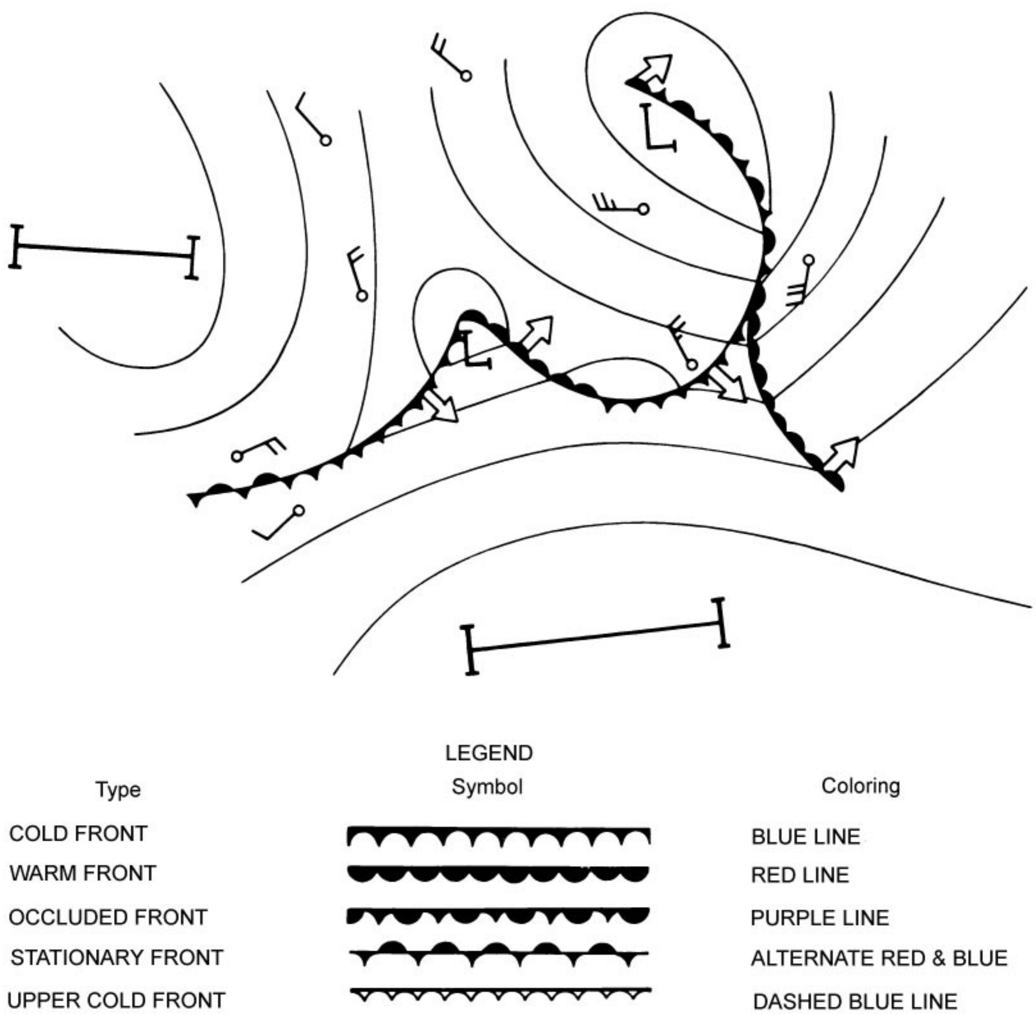


Figure 3525. Designation of fronts on weather maps.

Oceanography Command. This publication lists broadcast schedules and weather codes. Information on day and night visual storm warnings is given in the various volumes of Sailing Directions (Enroute), and (Planning Guide).

3526. Interpreting Weather

The factors which determine weather are numerous and varied. Ever-increasing knowledge regarding them makes possible a continually improving weather service. However, the ability to forecast is acquired through study and long practice, and therefore the services of a trained meteorologist should be utilized whenever available.

The value of a forecast is increased if one has access to the information upon which it is based, and understands the principles and processes involved. It is sometimes as important to know the various types of weather which may be experienced as it is to know which of several possibilities is most likely to occur.

At sea, reporting stations are unevenly distributed, sometimes leaving relatively large areas with incomplete reports, or none at all. Under these conditions, the locations of highs, lows, fronts, etc., are imperfectly known, and their very existence may even be in doubt. At such times the mariner who can interpret the observations made from his own vessel may be able to predict weather for the next several hours more reliably than a trained meteorologist ashore.

CHAPTER 36

TROPICAL CYCLONES

CAUSES AND DESCRIPTION OF TROPICAL CYCLONES

3600. Introduction

A **tropical cyclone** is a cyclone originating in the tropics or subtropics. Although it generally resembles the extratropical cyclone of higher latitudes, there are important differences, the principal one being the concentration of a large amount of energy into a relatively small area. Tropical cyclones are infrequent in comparison with middle and high latitude storms, but they have a record of destruction far exceeding that of any other type of storm. Because of their fury, and because they are predominantly oceanic, they merit special attention by mariners.

A tropical storm has a deceptively small size, and beautiful weather may be experienced only a few hundred miles from the center. The rapidity with which the weather can deteriorate with approach of the storm, and the violence of the fully developed tropical cyclone, are difficult to imagine if they have not been experienced.

On his second voyage to the New World, Columbus encountered a tropical storm. Although his vessels suffered no damage, this experience proved valuable during his fourth voyage when his ships were threatened by a fully developed hurricane. Columbus read the signs of an approaching storm from the appearance of a southeasterly swell, the direction of the high cirrus clouds, and the hazy appearance of the atmosphere. He directed his vessels to shelter. The commander of another group, who did not heed the signs, lost most of his ships and more than 500 men perished.

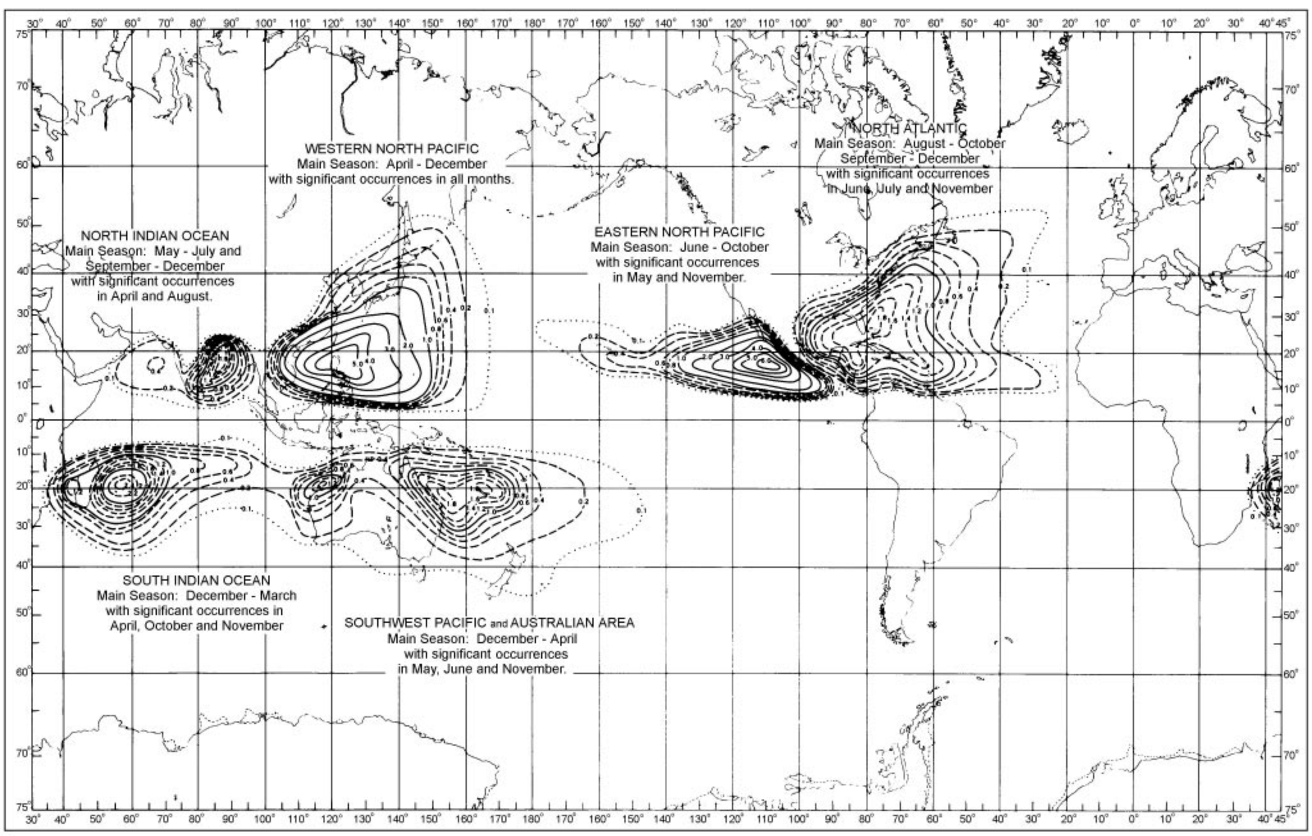


Figure 3602. Areas in which tropical cyclones occur. The average number of tropical cyclones per 5˚ square has been analyzed for this figure. The main season for intense tropical storm activity is also shown for each major basin.

3601. Definitions

"Tropical cyclone" is the term for cyclones originating in the tropics or subtropics. These cyclones are classified by form and intensity as they increase in size.

A **tropical disturbance** is a discrete system of apparently organized convection, generally 100 to 300 miles in diameter, having a nonfrontal migratory character, and having maintained its identity for 24 hours or more. It may or may not be associated with a detectable disturbance of the wind field. It has no strong winds and no closed isobars i.e., isobars that completely enclose the low.

At its next stage of development it becomes a **tropical depression**. A tropical depression has one or more closed isobars and some rotary circulation at the surface. The highest sustained (1-minute mean) surface wind speed is 33 knots.

The next stage is **tropical storm**. A tropical storm has closed isobars and a distinct rotary circulation. The highest sustained (1-minute mean) surface wind speed is 34 to 63 knots.

When fully developed, a **hurricane** or **typhoon** has closed isobars, a strong and very pronounced rotary circulation, and a sustained (1-minute mean) surface wind speed of 64 knots or higher.

3602. Areas Of Occurrence

Tropical cyclones occur almost entirely in six distinct areas, four in the Northern Hemisphere and two in the Southern Hemisphere as shown in Figure 3602. The name by which the tropical cyclone is commonly known varies somewhat with the locality.

1. North Atlantic. A tropical cyclone with winds of 64 knots or greater is called a **hurricane**.
2. Eastern North Pacific. The name **hurricane** is used as in the North Atlantic.
3. Western North Pacific. A fully developed storm with winds of 64 knots or greater is called a **typhoon** or, locally in the Philippines, a **baguio**.
4. North Indian Ocean. A tropical cyclone with winds of 34 knots or greater is called a **cyclonic storm**.
5. South Indian Ocean. A tropical cyclone with winds of 34 knots or greater is called a **cyclone**.
6. Southwest Pacific and Australian Area. The name **cyclone** is used as in the South Indian Ocean. A severe tropical cyclone originating in the Timor Sea and moving southwest and then southeast across the interior of northwestern Australia is called a **willy-willy**.

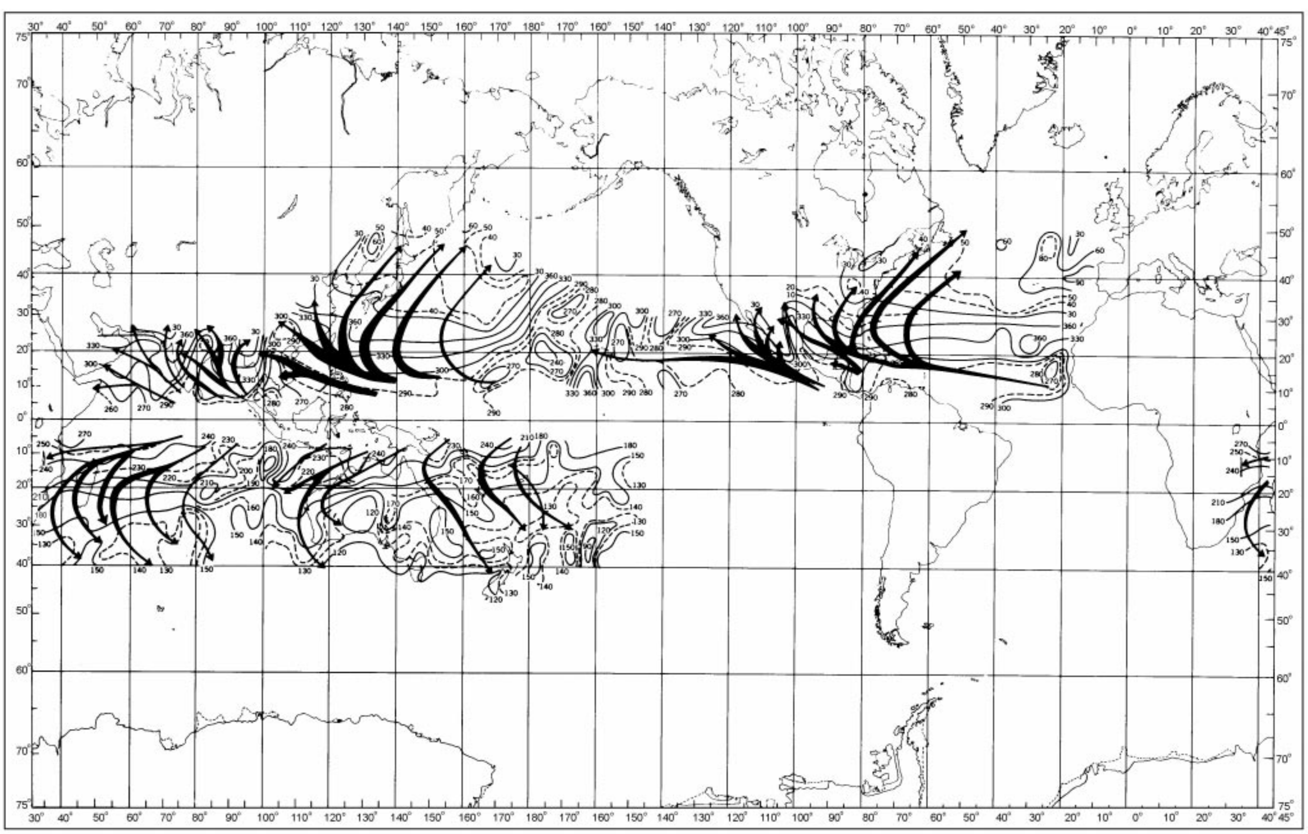


Figure 3603a. Storm tracks.The width of the arrow indicates the approximate frequency of storms; the wider the arrow the higher the frequency. Isolines on the base map show the resultant direction toward which storms moved. Data for the entire year has been summarized for this figure.

Tropical cyclones have not been observed in the South Atlantic or in the South Pacific east of 140°W.

3603. Origin, Season And Frequency

See Figures 3603a and 3603b. Origin, season, and frequency of occurrence of the tropical cyclones in the six areas are as follows:

North Atlantic: Tropical cyclones can affect the entire North Atlantic Ocean in any month. However, they are mostly a threat south of about 35°N from June through November; August, September, and October are the months of highest incidence. See Figure 3603b. About 9 or 10 tropical cyclones (tropical storms and hurricanes) form each season; 5 or 6 reach hurricane intensity (winds of 64 knots and higher). A few hurricanes have generated winds estimated as high as 200 knots. Early and late season storms usually develop west of 50°W; during August and September, this spawning ground extends to the Cape Verde Islands. These storms usually move westward or west northwestward at speeds of less than 15 knots in the lower latitudes. After moving into the northern Caribbean or Greater Antilles regions, they usually either move toward the Gulf of Mexico or recurve and accelerate in the North Atlantic. Some will recurve after reaching the Gulf of Mexico, while others will continue westward to a landfall in Texas or Mexico.

Eastern North Pacific: The season is from June through October, although a storm can form in any month. An average of 15 tropical cyclones form each year with about 6 reaching hurricane strength. The most intense storms are often the early- and late-season ones; these form close to the coast and far south. Mid season storms form anywhere in a wide band from the Mexican-Central American coast to the Hawaiian Islands. August and September are the months of highest incidence. These storms differ from their North Atlantic counterparts in that they are usually smaller in size. However, they can be just as intense.

Western North Pacific: More tropical cyclones form in the tropical western North Pacific than anywhere else in the world. More than 25 tropical storms develop each year, and about 18 become typhoons. These typhoons are the largest and most intense tropical cyclones in the world. Each year an average of five generate maximum winds over 130 knots; circulations covering more than 600 miles in diameter are not uncommon. Most of these storms form east

AREA AND STAGE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
NORTH ATLANTIC													
TROPICAL STORMS	*	*	*	*	0.1	0.4	0.3	1.0	1.5	1.2	0.4	*	4.2
HURRICANES	*	*	*	*	*	0.3	0.4	1.5	2.7	1.3	0.3	*	5.2
TROPICAL STORMS AND HURRICANES	*	*	*	*	*0.2*	*0.7*	*0.8*	*2.5*	*4.3*	*2.5*	*0.7*	*0.1*	*9.4*
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
EASTERN NORTH PACIFIC													
TROPICAL STORMS	*	*	*	*	*	1.5	2.8	2.3	2.3	1.2	0.3	*	9.3
HURRICANES	*	*	*	*	0.3	0.6	0.9	2.0	1.8	1.0	*	*	5.8
TROPICAL STORMS AND HURRICANES	*	*	*	*	*0.3*	*2.0*	*3.6*	*4.5*	*4.1*	*2.2*	*0.3*	*	*15.2*
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
WESTERN NORTH PACIFIC													
TROPICAL STORMS	0.2	0.3	0.3	0.2	0.4	0.5	1.2	1.8	1.5	1.0	0.8	0.6	7.5
TYPHOONS	0.3	0.2	0.2	0.7	0.9	1.2	2.7	4.0	4.1	3.3	2.1	0.7	17.8
TROPICAL STORMS AND TYPHOONS	*0.4*	*0.4*	*0.5*	*0.9*	*1.3*	*1.8*	*3.9*	*5.8*	*5.6*	*4.3*	*2.9*	*1.3*	*25.3*
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTHWEST PACIFIC AND AUSTRALIAN AREA													
TROPICAL STORMS	2.7	2.8	2.4	1.3	0.3	0.2	*	*	*	0.1	0.4	1.5	10.9
HURRICANES	0.7	1.1	1.3	0.3	*	*	0.1	0.1	*	*	0.3	0.5	3.8
TROPICAL STORMS AND HURRICANES	*3.4*	*4.1*	*3.7*	*1.7*	*0.3*	*0.2*	*0.1*	*0.1*	*	*0.1*	*0.7*	*2.0*	*14.8*
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
SOUTHWEST INDIAN OCEAN													
TROPICAL STORMS	2.0	2.2	1.7	0.6	0.2	*	*	*	*	0.3	0.3	0.8	7.4
HURRICANES	1.3	1.1	0.8	0.4	*	*	*	*	*	*	*	0.5	3.8
TROPICAL STORMS AND HURRICANES	*3.2*	*3.3*	*2.5*	*1.1*	*0.2*	*	*	*	*	*0.3*	*0.4*	*1.4*	*11.2*
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
NORTH INDIAN OCEAN													
TROPICAL STORMS	0.1	*	*	0.1	0.3	0.5	0.5	0.4	0.4	0.6	0.5	0.3	3.5
CYCLONES[1]	*	*	*	0.1	0.5	0.2	0.1	*	0.1	0.4	0.6	0.2	2.2
TROPICAL STORMS AND CYCLONES[1]	*0.1*	*	*0.1*	*0.3*	*0.7*	*0.7*	0.6	*0.4*	*0.5*	*1.0*	*1.1*	*0.5*	*5.7*

* Less than .05 [1] Winds $\geq$ 48 Kts.

Monthly values cannot be combined because single storms overlapping two months were counted once in each month and once in the annual.

Figure 3603b. Monthly and annual average number of storms per year for each area.

of the Philippines, and move across the Pacific toward the Philippines, Japan, and China; a few storms form in the South China Sea. The season extends from April through December. However, tropical cyclones are more common in the off-season months in this area than anywhere else. The peak of the season is July through October, when nearly 70 percent of all typhoons develop. There is a noticeable seasonal shift in storm tracks in this region. From July through September, storms move north of the Philippines and recurve, while early- and late-season typhoons move on a more westerly track through the Philippines before recurving.

North Indian Ocean—Tropical cyclones develop in the Bay of Bengal and Arabian Sea during the spring and fall. Tropical cyclones in this area form between latitudes 8°N and 15°N, except from June through September, when the little activity that does occur is confined north of about 15°N. These storms are usually short-lived and weak; however, winds of 130 knots have been encountered. They often develop as disturbances along the Intertropical Convergence Zone (ITCZ); this inhibits summertime development, since the ITCZ is usually over land during this monsoon season. However, it is sometimes displaced southward, and when this occurs, storms will form over the monsoon-flooded plains of Bengal. On the average, six cyclonic storms form each year. These include two storms that generate winds of 48 knots or greater. Another 10 tropical cyclones never develop beyond tropical depressions. The Bay of Bengal is the area of highest incidence. However, it is not unusual for a storm to move across southern India and reintensify in the Arabian Sea. This is particularly true during October, the month of highest incidence during the tropical cyclone season. It is also during this period that torrential rains from these storms, dumped over already rain-soaked areas, cause disastrous floods.

South Indian Ocean—Over the waters west of 100°E, to the east African coast, an average of 11 tropical cyclones (tropical storms and hurricanes) form each season, and about 4 reach hurricane intensity. The season is from December through March, although it is possible for a storm to form in any month. Tropical cyclones in this region usually form south of 10°S. The latitude of recurvature usually migrates from about 20°S in January to around 15°S in April. After crossing 30°S, these storms sometimes become intense extratropical lows.

Southwest Pacific and Australian Area—These tropical waters spawn an annual average of 15 tropical cyclones 4 of which reach hurricane intensity. The season extends from about December through April, although storms can form in any month. Activity is widespread in January and February, and it is in these months that tropical cyclones are most likely to affect Fiji, Samoa, and the other eastern islands. Tropical cyclones usually form in the waters from 105°E to 160°W, between 5° and 20°S. Storms affecting northern and western Australia often develop in the Timor or Arafura Sea, while those that affect the east coast form in the Coral Sea. These storms are often small, but can develop winds in excess of 130 knots. New Zealand is sometimes reached by decaying Coral Sea storms, and occasionally by an intense hurricane. In general, tropical cyclones in this region move southwestward and then recurve southeastward.

ANATOMY OF TROPICAL CYCLONES

3604. Formation

Hurricane formation was once believed to result from an intensification of convective forces which produce the towering cumulonimbus clouds of the doldrums. This view of hurricane generation held that surface heating caused warm moist air to ascend convectively to levels where condensation produced cumulonimbus clouds, which, after an inexplicable drop in atmospheric pressure, coalesced and were spun into a cyclonic motion by Coriolis force.

This hypothesis left much unexplained. Although some hurricanes develop from disturbances beginning in the doldrums, very few reach maturity in that region. Also, the high incidence of seemingly ideal convective situations does not match the low incidence of Atlantic hurricanes. Finally, the hypothesis did not explain the drop in atmospheric pressure, so essential to development of hurricane-force winds.

There is still no exact understanding of the triggering mechanism involved in hurricane generation, the balance of conditions needed to generate hurricane circulation, and the relationships between large- and small-scale atmospheric processes. But scientists today, treating the hurricane system as an atmospheric heat engine, present a more comprehensive and convincing view.

They begin with a starter mechanism in which either internal or external forces intensify the initial disturbance. The initial disturbance becomes a region into which low-level air from the surrounding area begins to flow, accelerating the convection already occurring inside the disturbance. The vertical circulation becomes increasingly well organized as water vapor in the ascending moist layer is condensed (releasing large amounts of heat energy to drive the wind system), and as the system is swept into a counterclockwise cyclonic spiral. But this incipient hurricane would soon fill up because of inflow at lower levels, unless the chimney in which converging air surges upward is provided the exhaust mechanism of high-altitude winds.

These high-altitude winds pump ascending air out of

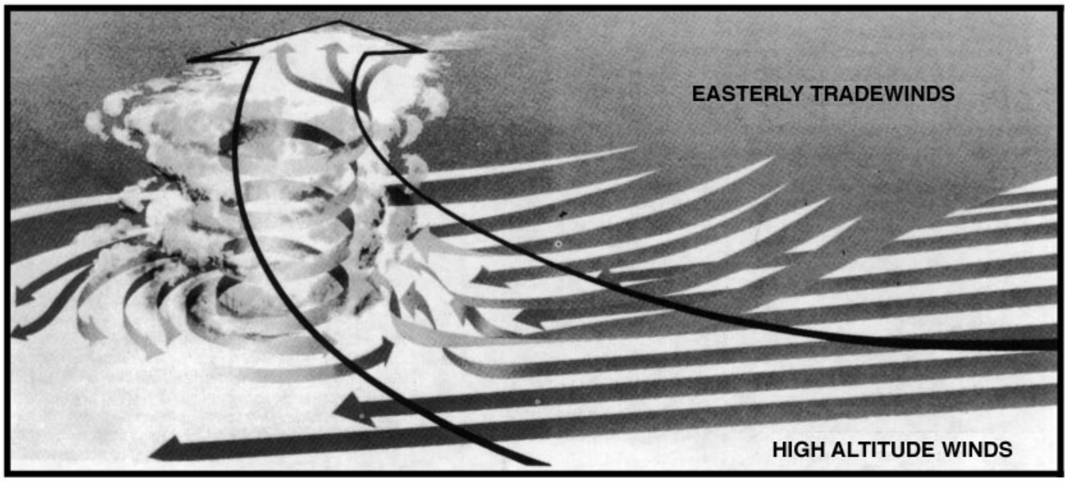


Figure 3604. Pumping action of high-altitude winds.

the cyclonic system, into a high-altitude anticyclone, which transports the air well away from the disturbance, before sinking occurs. Thus, a large scale vertical circulation is set up, in which low-level air is spiraled up the cyclonic twisting of the disturbance, and, after a trajectory over the sea, returned to lower altitudes some distance from the storm. This pumping action-and the heat released by the ascending air may account for the sudden drop of atmospheric pressure at the surface, which produces the steep pressure gradient along which winds reach hurricane proportions.

It is believed that the interaction of low-level and high-altitude wind systems determines the intensity the hurricane will attain. If less air is pumped out than converges at low levels, the system will fill and die out. If more is pumped out than flows in, the circulation will be sustained and will intensify.

Scientists have found that any process which increases the rate of low-level inflow is favorable for hurricane development, provided the inflowing air carries sufficient heat and moisture to fuel the hurricane's power system. It has also been shown that air above the developing disturbance, at altitudes between 20,000 and 40,000 feet, increases 1° to 3° in temperature about 24 hours before the disturbance develops into a hurricane. But it is not known whether low-level inflow and high-level warming cause hurricanes. They could very well be measurable symptoms of another effect which actually triggers the storm's increase to hurricane intensity.

The view of hurricanes as atmospheric engines is necessarily a general one. The exact role of each contributor is not completely understood. The engine seems to be both inefficient and unreliable; a myriad of delicate conditions must be satisfied for the atmosphere to produce a hurricane. Their relative infrequency indicates that many potential hurricanes dissipate before developing into storms.

3605. Portrait Of A Hurricane

In the early life of the hurricane, the spiral covers an area averaging 100 miles in diameter with winds of 64 knots and greater, and spreads gale-force winds over a 400-mile diameter. The cyclonic spiral is marked by heavy cloud bands from which torrential rains fall, separated by areas of light rain or no rain at all. These spiral bands ascend in decks of cumulus and cumulonimbus clouds to the convective limit of cloud formation, where condensing water vapor is swept off as ice-crystal wisps of cirrus clouds. Thunderstorm electrical activity is observed in these bands, both as lightning and as tiny electrostatic discharges.

In the lower few thousand feet, air flows in through the cyclone, and is drawn upward through ascending columns of air near the center. The size and intensity decrease with altitude, the cyclonic circulation being gradually replaced above 40,000 feet by an anticyclonic circulation centered hundreds of miles away, which is the exhaust system of the hurricane heat engine.

At lower levels, where the hurricane is more intense, winds on the rim of the storm follow a wide pattern, like the slower currents around the edge of a whirlpool; and, like those currents, these winds accelerate as they approach the center of the vortex. The outer band has light winds at the rim of the storm, perhaps no more than 25 knots; within 30 miles of the center, winds may have velocities exceeding 130 knots. The inner band is the region of maximum wind velocity, where the storm's worst winds are felt, and where ascending air is chimneyed upward, releasing heat to drive the storm. In most hurricanes, these winds reach 85 knots, and more than 170 knots in severe storms.

In the hurricane, winds flow toward the low pressure in the warm, comparatively calm core. There, converging air is whirled upward by convection, the mechanical thrusting of other converging air, and the pumping action of high-altitude circulations. This spiral is marked by the thick cloud walls curling inward toward the storm center, releasing heavy precipitation and enormous quantities of heat energy. At the center, surrounded by a band in which this strong vertical circulation is greatest, is the **eye** of the hurricane.

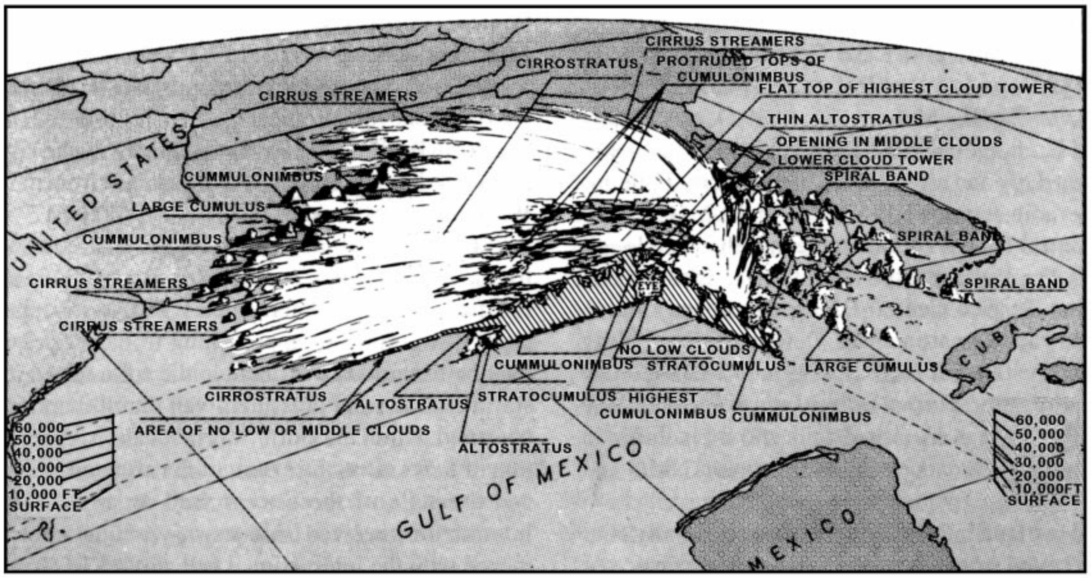


Figure 3605. Cutaway view of a hurricane greatly exaggerated in vertical dimension. Actual hurricanes are less than 50,000 feet high and may have a diameter of several hundred miles.

On the average, eye diameter is about 14 miles, although diameters of 25 miles are not unusual. From the heated tower of maximum winds and cumulonimbus clouds, winds diminish rapidly to something less than 15 miles per hour in the eye; at the opposite wall, winds increase again, but come from the opposite direction because of the cyclonic circulation of the storm. This sudden transformation of storm into comparative calm, and from calm into violence from another quarter is spectacular. The eye's abrupt existence in the midst of opaque rain squalls and hurricane winds, the intermittent bursts of blue sky and sunlight through light clouds in the core of the cyclone, and the galleried walls of cumulus and cumulonimbus clouds are unforgettable.

Every hurricane is individual, and the more or less orderly circulation described here omits the extreme variability and instability within the storm system. Pressure and temperature gradients fluctuate wildly across the storm as the hurricane maintains its erratic life. If it is an August storm, its average life expectancy is 12 days; if a July or November storm, it lives an average of 8 days.

3606. Life Of A Tropical Cyclone

Reports from ships in the vicinity of an **easterly wave** (a westward-moving trough of low pressure embedded in deep easterlies) may indicate that the atmospheric pressure in the region has fallen more than 5 millibars in the past 24 hours. This is cause for alarm, because in the Tropics pressure varies little; the normal diurnal pressure change is only about 3 millibars. Satellite pictures may indicate thickening middle and high clouds. Squalls are reported ahead of the easterly wave, and wind reports indicate a cyclonic circulation is forming. The former easterly wave, now classified a tropical disturbance, is moving westward at 10 knots under the canopy of a large high-pressure system aloft. Sea surface temperatures in the vicinity are in the 28°-30°C range.

Within 48 hours winds increase to 25 knots near the center of definite circulation, and central pressure has dropped below 1000 millibars. The disturbance is now classified as a tropical depression. Soon the circulation extends out to 100 miles and upward to 20,000 feet. Winds near the center increase to gale force, central pressure falls below 990 millibars, and towering cumulonimbus clouds shield a developing eye; a tropical storm has developed.

Satellite photographs now reveal a tightly organized tropical cyclone, and reconnaissance reports indicate maximum winds of 80 knots around a central pressure of 980 millibars; a hurricane has developed. A ship to the right (left in the Southern Hemisphere) of the hurricane's center (looking toward the direction of storm movement) reports 30-foot seas. The hurricane is rapidly maturing as it continues westward.

A few days later the hurricane reaches its peak. The satellite photographs show a textbook picture, as 120-knot winds roar around a 940-millibar pressure center; hurricane-force winds extend 50 miles in all directions, and seas are reported up to 40 feet. There is no further deepening now, but the hurricane begins to expand. In 2 days, gales extend out to 200 miles, and hurricane winds out to 75 miles. Then the hurricane slows and begins to recurve; this turning marks the beginning of its final phase.

The hurricane accelerates, and, upon reaching temper-

ate latitudes, it begins to lose its tropical characteristics. The circulation continues to expand, but now cold air is intruding (cold air, cold water, dry air aloft, and land, aid in the decay of a tropical cyclone). The winds gradually abate as the concentrated storm disintegrates. The warm core survives for a few more days before the transformation to a large extratropical low-pressure system is complete.

Not all tropical cyclones follow this average pattern. Most falter in the early stages, some dissipate over land, and others remain potent for several weeks.

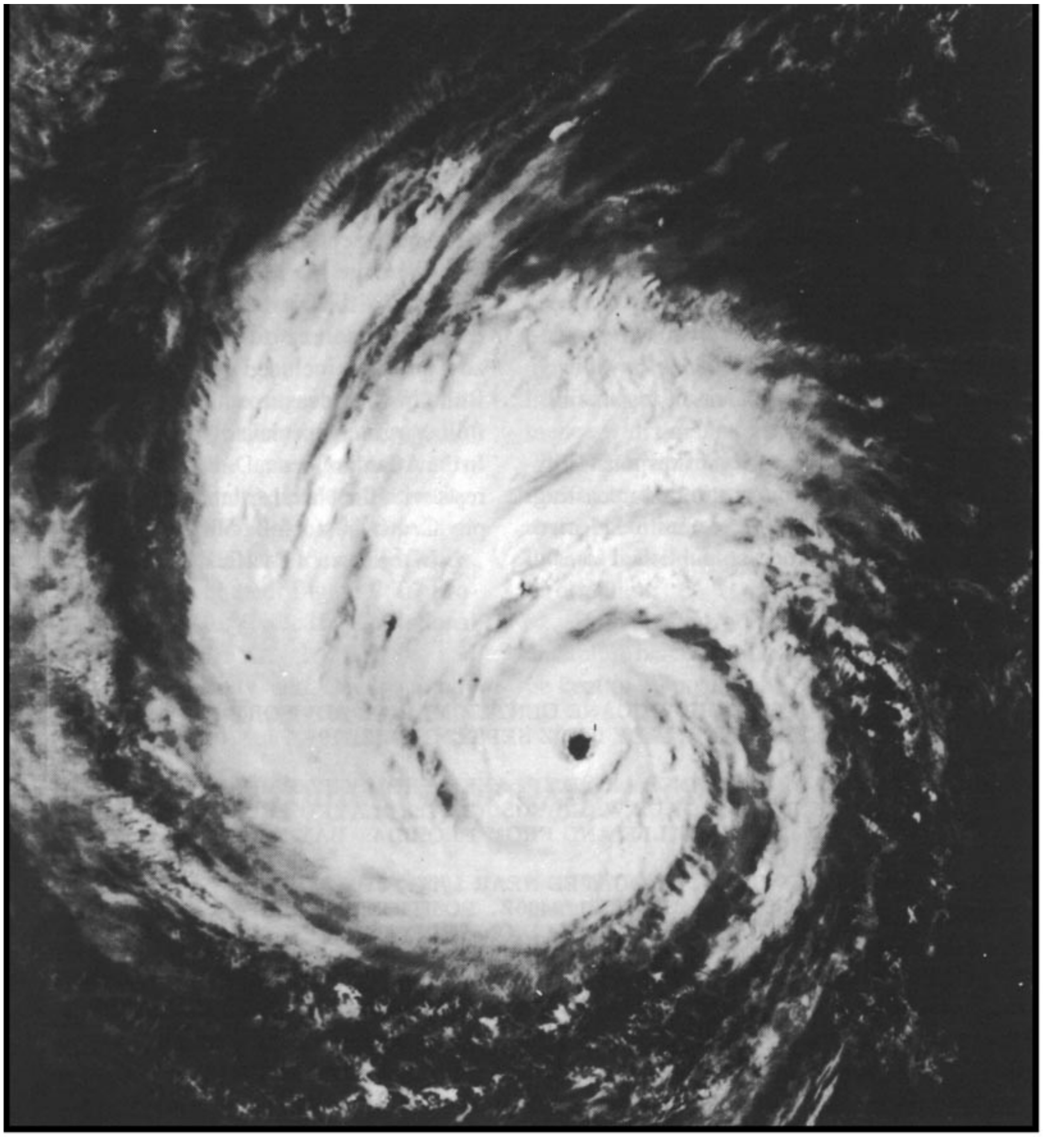


Figure 3606. Satellite photograph of a hurricane.

FORECASTING AND PREDICTING TROPICAL CYCLONES

3607. Weather Broadcasts And Radiofacsimile

The marine weather broadcast and radiofacsimile weather maps are the most important tools for avoiding tropical cyclones. These broadcasts, covering all tropical areas, provide information about the tropical cyclone's location, maximum winds and seas, and future conditions expected.

The U S. Navy, the National Oceanic and Atmospheric Administration, and the U.S. Air Force have developed a highly effective surveillance system for the tropical cy-

clone-prone areas of the world. Routine and special weather reports (from land stations, ships at sea, aircraft; weather satellite imagery; radar reports from land stations; special reports from ships at sea; and the specially instrumented weather reconnaissance aircraft of National Oceanic and Atmospheric Administration and the U.S. Air Force) enable accurate detection, location, and tracking of tropical cyclones. International cooperation is effective. Data buoys, both moored and drifting, provide another source of information.

The tropical warning services have three principal functions:

1. The collection and analysis of the necessary observational data.
2. The preparation of timely and accurate forecasts and warnings.
3. The rapid and efficient distribution of advisories, warnings, and all other pertinent information.

To provide timely and accurate information and warnings regarding tropical cyclones, the oceans have been divided into overlapping geographical areas of responsibility.

For detailed information on the areas of responsibility of the countries participating in the international forecasting and warning program, and radio aids, refer to Selected Worldwide Marine Weather Broadcasts, published jointly by the Naval Meteorology and Oceanography Command and the National Weather Service.

Although the areas of forecasting responsibility are fairly well defined for the Department of Defense, the international and domestic civilian system provides many overlaps and is dependent upon qualitative factors. For example, when a tropical storm or hurricane is traveling westward and crosses 35°W longitude, the continued issuance of forecasts and warnings to the general public, shipping interests, etc., becomes the responsibility of the National Hurricane Center of the National Weather Service at Miami, Florida. When a tropical storm or hurricane crosses 35°W longitude traveling from west to east, the National Hurricane Center ceases to issue formal public advisories, but will issue marine bulletins on any dangerous tropical cyclone in the North Atlantic, if it is of importance or constitutes a threat to shipping and other interests. These advisories are included in National Weather Service Marine Bulletins broadcast to ships over radio station NAM Norfolk, Virginia. Special advisories may be issued at any time. In the Atlantic Ocean, Department of Defense responsibility rests with the Naval Atlantic Meteorology and Oceanography Center in Norfolk, Virginia.

In the eastern Pacific east of longitude 140°W, respon-

NOAA/NATIONAL HURRICANE CENTER MARINE ADVISORY NUMBER 13 HURRICANE LADY 0400Z SEPTEMBER 21 19--.

HURRICANE WARNINGS ARE DISPLAYED FROM KEY LARGO TO CAPE KENNEDY. GALE WARNINGS ARE DISPLAYED FROM KEY WEST TO JACKSONVILLE AND FROM FLORIDA BAY TO CEDAR KEY.

HURRICANE CENTER LOCATED NEAR LATITUDE 25.5 NORTH LONGITUDE 78.5 WEST AT 21/0400Z. POSITION EXCELLENT ACCURATE WITHIN 10 MILES BASED ON AIR FORCE RECONNAISSANCE AND SYNOPTIC REPORTS.

PRESENT MOVEMENT TOWARD THE WEST NORTHWEST OR 285 DEGREES AT 10 KT. MAX SUSTAINED WINDS OF 100 KT NEAR CENTER WITH GUSTS TO 160 KT.
MAX WINDS OVER INLAND AREAS 35 KT.
RAD OF 65 KT WINDS 90 NE 60 SE 80 SW 90 NW QUAD.
RAD OF 50 KT WINDS 120 NE 70 SE 90 SW 120 NW QUAD.
RAD OF 30 KT WINDS 210 NE 210 SE 210 SW 210 NW QUAD.
REPEAT CENTER LOCATED 25.5N 78.3W AT 21/0400Z.

12 HOUR FORECAST VALID 21/1600Z LATITUDE 26.0N LONGITUDE 80.5W.
MAX WINDS OF 100 KT NEAR CENTER WITH GUSTS TO 160 KT.
MAX WINDS OVER INLAND AREAS 65 KT.
RADIUS OF 50 KT WINDS 120 NE 70 SE 90 SW 120 NW QUAD.
24 HOUR FORECAST VALID 22/0400Z LATITUDE 26.0N LONGITUDE 83.0W.
MAX WINDS OF 75 KT NEAR CENTER WITH GUSTS TO 120 KT.
MAX WINDS OVER INLAND AREAS 45 KT.
RADIUS OF 50 KT WINDS 120 NE 120 SE 120 SW 120 NW QUAD.

STORM TIDE OF 9 TO 12 FT SOUTHEAST FLA COAST GREATER MIAMI AREA TO THE PALM BEACHES.

NEXT ADVISORY AT 21/1000Z.

Figure 3607. Example of marine advisory issued by National Hurricane Center.

sibility for the issuance of tropical storm and hurricane advisories and warnings for the general public, merchant shipping, and other interests rests with the National Weather Service Eastern Pacific Hurricane Center, San Francisco, California. The Department of Defense responsibility rests with the Naval Pacific Meteorology and Oceanography Center, Pearl Harbor, Hawaii. Formal advisories and warnings are issued daily and are included in the marine bulletins broadcast by radio stations KFS, NMC, and NMQ.

In the central Pacific (between the meridian and longitude 140°W), the civilian responsibility rests with the National Weather Service Central Pacific Hurricane Center, Honolulu, Hawaii. Department of Defense responsibility rests with the Naval Pacific Meteorology and Oceanography Center in Pearl Harbor. Formal tropical storm and hurricane advisories and warnings are issued daily and are included in the marine bulletins broadcast by radio station NMO and NRV.

Tropical cyclone information messages generally contain position of the storm, intensity, direction and speed of movement, and a description of the area of strong winds. Also included is a forecast of future movement and intensity. When the storm is likely to affect any land area, details on when and where it will be felt, and data on tides, rain, floods, and maximum winds are also included. Figure 3607 provides an example of a marine advisory issued by the National Hurricane Center.

The Naval Pacific Meteorology and Oceanography Center Center-West/Joint Typhoon Warning Center (NPMOC-W/JTWC) in Guam is responsible for all U.S. tropical storm and typhoon advisories and warnings from the 180th meridian westward to the mainland of Asia. A secondary area of responsibility extends westward to longitude 90°E. Whenever a tropical cyclone is observed in the western North Pacific area, serially numbered warnings, bearing an “immediate” precedence are broadcast from the NPMOC-W/JTWC at 0000, 0600, 1200, and 1800 GMT.

The responsibility for issuing gale and storm warnings for the Indian Ocean, Arabian Sea, Bay of Bengal, Western Pacific, and South Pacific rests with many countries. In general, warnings of approaching tropical cyclones which may be hazardous will include the following information: storm type, central pressure given in millibars, wind speed observed within the storm, storm location, speed and direction of movement, the extent of the affected area, visibility, and the state of the sea, as well as any other pertinent information received. All storm warning messages commence with the international call sign “TTT.”

These warnings are broadcast on specified radio frequency bands immediately upon receipt of the information and at specific intervals thereafter. Generally, the broadcast interval is every 6 to 8 hours, depending upon receipt of new information.

Bulletins and forecasts are excellent guides to the present and future behavior of the tropical cyclone, and a plot should be kept of all positions.

AVOIDING TROPICAL CYCLONES

3608. Approach And Passage Of A Tropical Cyclone

An early indication of the approach of a tropical cyclone is the presence of a long swell. In the absence of a tropical cyclone, the crests of swell in the deep waters of the Atlantic pass at the rate of perhaps eight per minute. Swell generated by a hurricane is about twice as long, the crests passing at the rate of perhaps four per minute. Swell may be observed several days before arrival of the storm.

When the storm center is 500 to 1,000 miles away, the barometer usually rises a little, and the skies are relatively clear. Cumulus clouds, if present at all, are few in number and their vertical development appears suppressed. The barometer usually appears restless, pumping up and down a few hundredths of an inch.

As the tropical cyclone comes nearer, a cloud sequence begins which resembles that associated with the approach of a warm front in middle latitudes. Snow-white, fibrous “mare’s tails” (cirrus) appear when the storm is about 300 to 600 miles away. Usually these seem to converge, more or less, in the direction from which the storm is approaching. This convergence is particularly apparent at about the time of sunrise and sunset.

Shortly after the cirrus appears, but sometimes before, the barometer starts a long, slow fall. At first the fall is so gradual that it only appears to alter somewhat the normal daily cycle (two maxima and two minima in the Tropics). As the rate of fall increases, the daily pattern is completely lost in the more or less steady fall.

The cirrus becomes more confused and tangled, and then gradually gives way to a continuous veil of cirrostratus. Below this veil, altostratus forms, and then stratocumulus. These clouds gradually become more dense, and as they do so, the weather becomes unsettled. A fine, mist-like rain begins to fall, interrupted from time to time by rain showers. The barometer has fallen perhaps a tenth of an inch.

As the fall becomes more rapid, the wind increases in gustiness, and its speed becomes greater, reaching perhaps 22 to 40 knots (Beaufort 6-8). On the horizon appears a dark wall of heavy cumulonimbus, called the **bar** of the storm. This is the heavy bank of clouds comprising the main mass of the cyclone. Portions of this heavy cloud become detached from time to time, and drift across the sky, accompanied by rain squalls and wind of increasing speed. Between squalls, the cirrostratus can be seen through breaks in the stratocumulus.

As the bar approaches, the barometer falls more rapidly and wind speed increases. The seas, which have been gradu-

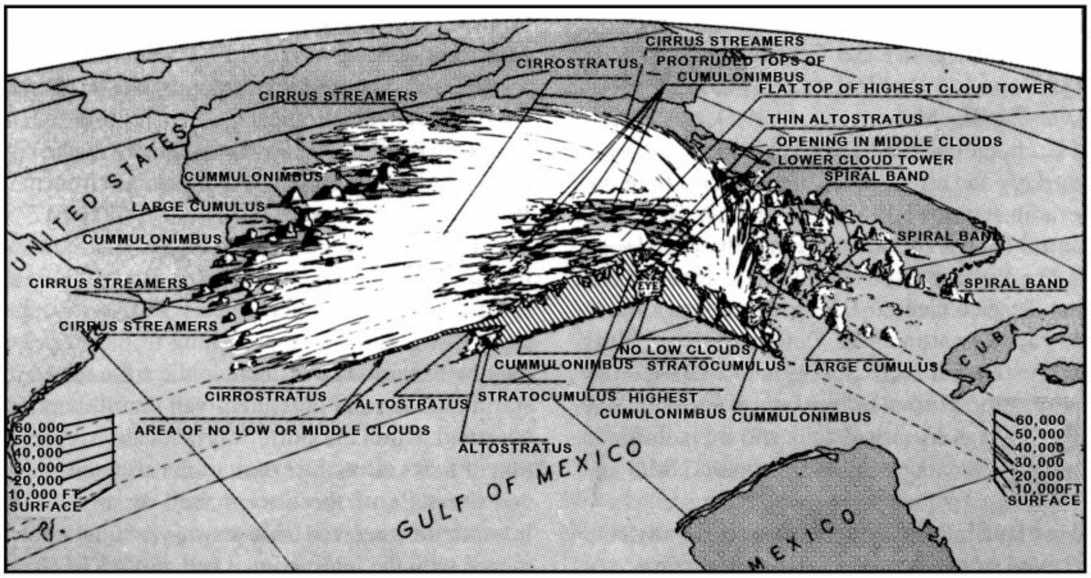


Figure 3608. Typical hurricane cloud formations.

ally mounting, become tempestuous. Squall lines, one after the other, sweep past in ever increasing number and intensity.

With the arrival of the bar, the day becomes very dark, squalls become virtually continuous, and the barometer falls precipitously, with a rapid increase in wind speed. The center may still be 100 to 200 miles away in a fully developed tropical cyclone. As the center of the storm comes closer, the ever-stronger wind shrieks through the rigging, and about the superstructure of the vessel. As the center approaches, rain falls in torrents. The wind fury increases. The seas become mountainous. The tops of huge waves are blown off to mingle with the rain and fill the air with water. Visibility is virtually zero in blinding rain and spray. Even the largest and most seaworthy vessels become virtually unmanageable, and may sustain heavy damage. Less sturdy vessels may not survive. Navigation virtually stops as safety of the vessel becomes the only consideration. The awesome fury of this condition can only be experienced. Words are inadequate to describe it.

If the eye of the storm passes over the vessel, the winds suddenly drop to a breeze as the wall of the eye passes. The rain stops, and the skies clear sufficiently to permit the sun or stars to shine through holes in the comparatively thin cloud cover. Visibility improves. Mountainous seas approach from all sides in complete confusion. The barometer reaches its lowest point, which may be 1 $^1/_2$ or 2 inches below normal in fully developed tropical cyclones. As the wall on the opposite side of the eye arrives, the full fury of the wind strikes as suddenly as it ceased, but from the opposite direction. The sequence of conditions that occurred during approach of the storm is reversed, and passes more quickly, as the various parts of the storm are not as wide in the rear of a storm as on its forward side.

Typical cloud formations associated with a hurricane are shown in Figure 3608.

3609. Locating The Center Of A Tropical Cyclone

If intelligent action is to be taken to avoid the full fury of a tropical cyclone, early determination of its location and direction of travel relative to the vessel is essential. The bulletins and forecasts are an excellent general guide, but they are not infallible, and may be sufficiently in error to induce a mariner in a critical position to alter course so as to unwittingly increase the danger to his vessel. Often it is possible, using only those observations made aboard ship, to obtain a sufficiently close approximation to enable the vessel to maneuver to the best advantage.

The presence of an exceptionally long swell is usually the first visible indication of the existence of a tropical cyclone. In deep water it approaches from the general direction of origin (the position of the storm center when the swell was generated). However, in shoaling water this is a less reliable indication because the direction is changed by refraction, the crests being more nearly parallel to the bottom contours.

When the cirrus clouds appear, their point of convergence provides an indication of the direction of the storm center. If the storm is to pass well to one side of the observer, the point of convergence shifts slowly in the direction of storm movement. If the storm center will pass near the observer, this point remains steady. When the bar becomes visible, it appears to rest upon the horizon for several hours. The darkest part of this cloud is in the direction of the storm center. If the storm is to pass to one side, the bar appears to drift slowly along the horizon. If the storm is heading di-

rectly toward the observer, the position of the bar remains fixed. Once within the area of the dense, low clouds, one should observe their direction of movement, which is almost exactly along the isobars, with the center of the storm being 90° from the direction of cloud movement (left of direction of movement in the Northern Hemisphere, and right in the Southern Hemisphere).

The winds are probably the best guide to the direction of the center of a tropical cyclone. The circulation is cyclonic, but because of the steep pressure gradient near the center, the winds there blow with greater violence and are more nearly circular than in extratropical cyclones.

According to **Buys Ballot's law**, an observer whose back is to the wind has the the low pressure on his left in the Northern Hemisphere, and on his right in the Southern Hemisphere. If the wind followed circular isobars exactly, the center would be exactly 90° from behind when facing away from the wind. However, the track of the wind is usually inclined somewhat toward the center, so that the angle from dead astern varies between perhaps 90° to 135°. The inclination varies in different parts of the same storm. It is least in front of the storm, and greatest in the rear, since the actual wind is the vector sum of the pressure gradient and the motion of the storm along the track. A good average is perhaps 110° in front, and 120-135° in the rear. These values apply when the storm center is still several hundred miles away. Closer to the center, the wind blows more nearly along the isobars, the inclination being reduced by one or two points at the wall of the eye. Since wind direction usually shifts temporarily during a squall, its direction at this time should not be used for determining the position of the center. The approximate relationship of wind to isobars and storm center in the Northern Hemisphere is shown in Figure 3609a.

When the center is within radar range, it will probably be visible on the scope. However, since the radar return is predominantly from the rain, results can be deceptive, and other indications should not be neglected. Figure 3609b shows a radar PPI presentation of a tropical cyclone. If the eye is out of range, the spiral bands (Figure 3609b) may indicate its direction from the vessel. Tracking the eye or upwind portion of the spiral bands enables determining the direction and speed of movement; this should be done for at

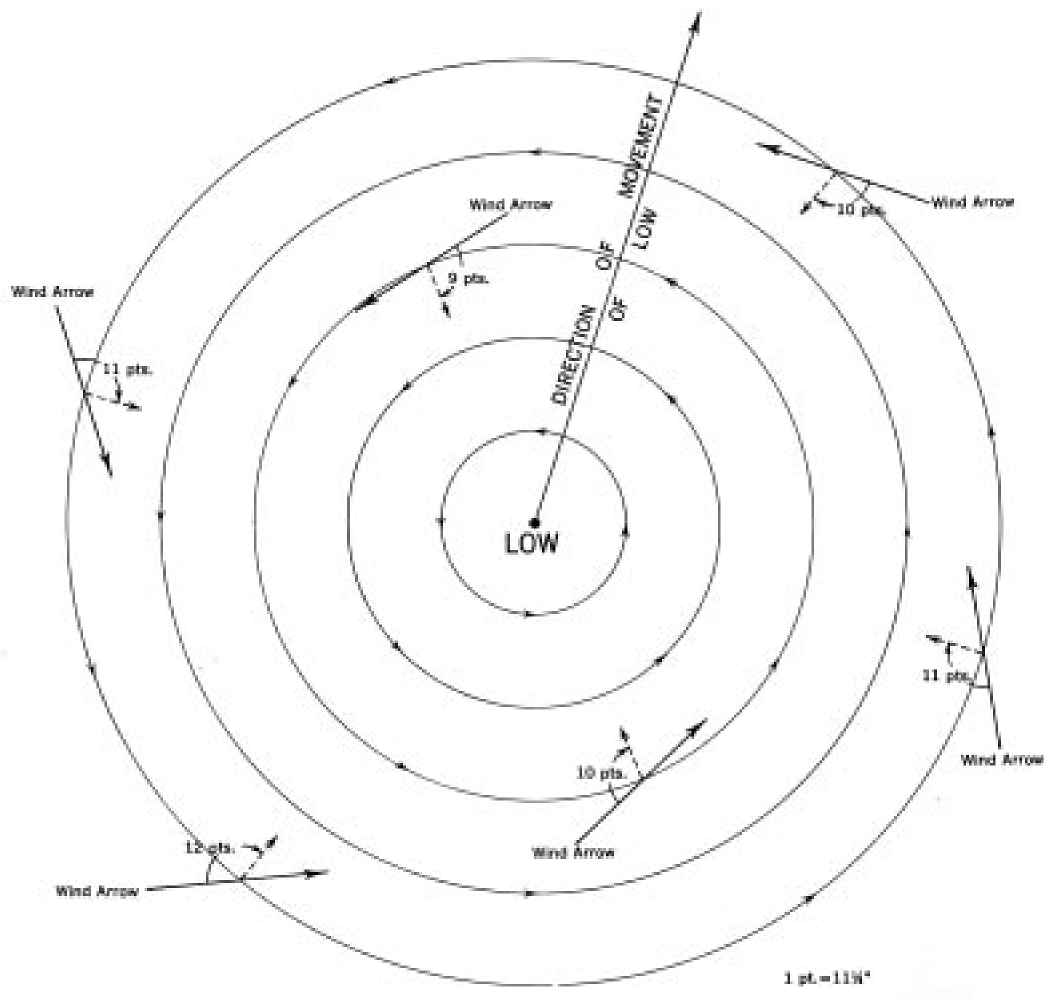


Figure 3609a. Approximate relationship of wind to isobars and storm center in the Northern Hemisphere.

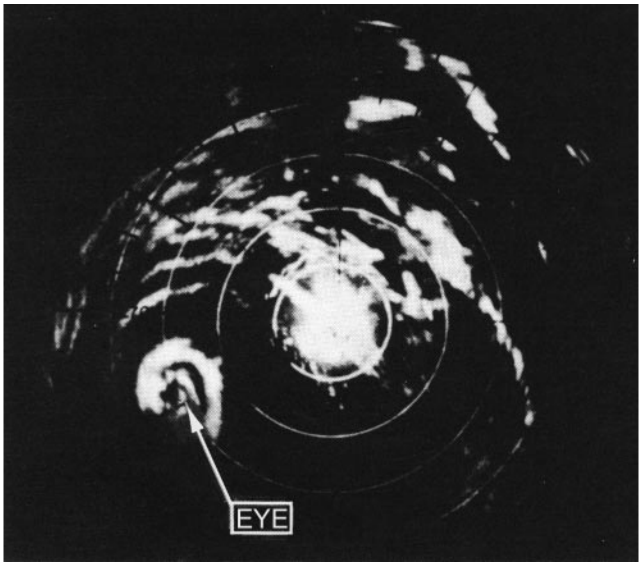


Figure 3609b. Radar PPI presentation of a tropical cyclone.

least 1 hour because the eye tends to oscillate. The tracking of individual cells, which tend to move tangentially around the eye, for 15 minutes or more, either at the end of the band or between bands, will provide an indication of the wind speed in that area of the storm.

Distance from the storm center is more difficult to determine than direction. Radar is perhaps the best guide. However, the rate of fall of the barometer is some indication.

3610. Statistical Analysis Of Barometric Pressure

The lowest-sea-level pressure ever recorded was 877 millibars in typhoon Ida, on September 24, 1958. The observation was taken by a reconnaissance aircraft dropsonde, some 750 miles east of Luzon, Philippines. This observation was obtained again in typhoon Nora on October 6, 1973. The lowest barometric reading of record for the United States is 892.3 millibars, obtained during a hurricane at Lower Matecumbe Key, Florida, in September 1935. In hurricane Camille in 1969, a 905 millibar pressure was measured by reconnaissance aircraft. During a 1927 typhoon, the S.S. Sapoeroea recorded a pressure of 886.6 millibars, the lowest sea-level pressure reported from a ship. Pressure has been observed to drop more than 33 millibars per hour, with a pressure gradient amounting to a change of 3.7 millibars per mile.

A method for alerting the mariner to possible tropical cyclone formation involves a statistical comparison of observed weather parameters with the climatology (30 year averaged conditions) for those parameters. Significant fluctuations away from these average conditions could mean the onset of severe weather. One such statistical method involves a comparison of mean surface pressure in the tropics with the standard deviation (s.d.) of surface pressure. Any significant deviation from the norm could indicate proximity to a tropical cyclone. Analysis shows that surface pressure can be expected to be lower than the mean minus 1 s.d. less than 16% of the time, lower than the mean minus 1.5 s.d. less than 7% of the time, and lower than the mean minus 2 s.d. less than 3% of the time. Comparison of the observed pressure with the mean will indicate how "unusual" the present conditions are.

As an example, assume the mean surface pressure in the South China Sea to be about 1005 mb during August with a s.d. of about 2 mb. Therefore, surface pressure can be expected to fall below 1003 mb about 16% of the time and below 1000 mb about 7% of the time. Ambient pressure any lower than that would alert the mariner to the possible onset of heavy weather. Charts showing the mean surface pressure and the s.d. of surface pressure for various global regions can be found in the U.S. Navy Marine Climatic Atlas of the World.

3611. Maneuvering To Avoid The Storm Center

The safest procedure with respect to tropical cyclones is to avoid them. If action is taken sufficiently early, this is simply a matter of setting a course that will take the vessel well to one side of the probable track of the storm, and then continuing to plot the positions of the storm center as given in the weather bulletins, revising the course as needed.

However, this is not always possible. If the ship is found to be within the storm area, the proper action to take depends in part upon its position relative to the storm center and its direction of travel. It is customary to divide the circular area of the storm into two parts.

In the Northern Hemisphere, that part to the right of the storm track (facing in the direction toward which the storm is moving) is called the **dangerous semicircle**. It is considered dangerous because (1) the actual wind speed is greater than that due to the pressure gradient alone, since it is augmented by the forward motion of the storm, and (2) the direction of the wind and sea is such as to carry a vessel into the path of the storm (in the forward part of the semicircle).

The part to the left of the storm track is called the **less dangerous semicircle**, or **navigable semicircle**. In this part, the wind is decreased by the forward motion of the storm, and the wind blows vessels away from the storm track (in the forward part). Because of the greater wind speed in the dangerous semicircle, the seas are higher than in the less dangerous semicircle. In the Southern Hemisphere, the dangerous semicircle is to the left of the storm track, and the less dangerous semicircle is to the right of the storm track.

A plot of successive positions of the storm center should indicate the semicircle in which a vessel is located. However, if this is based upon weather bulletins, it may not be a reliable guide because of the lag between the observations upon which the bulletin is based and the time of reception of the bulletin, with the ever-present possibility of a change in the direction of the storm. The use of radar eliminates this lag at short range, but the return may not be a true indication of the center. Perhaps the most reliable guide is the wind. Within

the cyclonic circulation, a wind shifting to the right in the northern hemisphere and to the left in the southern hemisphere indicates the vessel is probably in the dangerous semicircle. A steady wind shift opposite to this indicates the vessel is probably in the less dangerous semicircle.

However, if a vessel is underway, its own motion should be considered. If it is outrunning the storm or pulling rapidly toward one side (which is not difficult during the early stages of a storm, when its speed is low), the opposite effect occurs. This should usually be accompanied by a rise in atmospheric pressure, but if motion of the vessel is nearly along an isobar, this may not be a reliable indication. If in doubt, the safest action is usually to stop long enough to define the proper semicircle. The loss in time may be more than offset by the minimizing of the possibility of taking the wrong action, increasing the danger to the vessel. If the wind direction remains steady (for a vessel which is stopped), with increasing speed and falling barometer, the vessel is in or near the path of the storm. If it remains steady with decreasing speed and rising barometer, the vessel is near the storm track, behind the center.

The first action to take if the ship is within the cyclonic circulation is to determine the position of his vessel with respect to the storm center. While the vessel can still make considerable way through the water, a course should be selected to take it as far as possible from the center. If the vessel can move faster than the storm, it is a relatively simple matter to outrun the storm if sea room permits. But when the storm is faster, the solution is not as simple. In this case, the vessel, if ahead of the storm, will approach nearer to the center. The problem is to select a course that will produce the greatest possible minimum distance. This is best determined by means of a relative movement plot, as shown in the following example solved on a maneuvering board.

Example: *A tropical cyclone is estimated to be moving in direction 320° at 19 knots. Its center bears 170°, at an estimated distance of 200 miles from a vessel which has a maximum speed of 12 knots.*

Required:

(1) *The course to steer at 12 knots to produce the greatest possible minimum distance between the vessel and the storm center*.
(2) *The distance to the center at nearest approach*.
(3) *Elapsed time until nearest approach*.

Solution: *(Figure 3611) Consider the vessel remaining at the center of the plot throughout the solution, as on a radar PPI.*

(1) To locate the position of the storm center relative to the vessel, plot point C at a distance of 200 miles (scale 20:1) in direction 170° from the center of the diagram. From the center of the diagram, draw RA, the speed vector of the storm center, in direction 320°, speed 19 knots (scale 2:1). From A draw a line tangent to the 12-knot speed circle (labeled 6 at scale 2:1) on the side opposite the storm center. From the center of the diagram, draw a perpendicular to this tangent line, locating point B. The line RB is the required speed vector for the vessel. Its direction, 011°, is the required course.

(2) The path of the storm center relative to the vessel will be along a line from C in the direction BA, if both storm and vessel maintain course and speed. The point of nearest approach will be at D, the foot of a perpendicular from the center of the diagram. This distance, at scale 20:1, is 187 miles.

(3) The length of the vector BA (14.8 knots) is the speed of the storm with respect to the vessel. Mark this on the lowest scale of the nomogram at the bottom of the diagram. The relative distance CD is 72 miles, by measurement. Mark this (scale 10:1) on the middle scale at the bottom of the diagram. Draw a line between the two points and extend it to intersect the top scale at 29.2 (292 at 10:1 scale). The elapsed time is therefore 292 minutes, or 4 hours 52 minutes.

Answers: *(1) C 011°, (2) D 187 mi., (3) $4^h\ 52^m$.*
The storm center will be dead astern at its nearest approach.

As a general rule, for a vessel in the Northern Hemisphere, safety lies in placing the wind on the starboard bow in the dangerous semicircle and on the starboard quarter in the less dangerous semicircle. If on the storm track ahead of the storm, the wind should be put about 160° on the starboard quarter until the vessel is well within the less dangerous semicircle, and the rule for that semicircle then followed. In the Southern Hemisphere the same rules hold, but with respect to the port side. With a faster than average vessel, the wind can be brought a little farther aft in each case. However, as the speed of the storm increases along its track, the wind should be brought farther forward. If land interferes with what would otherwise be the best maneuver, the solution should be altered to fit the circumstances.

If the vessel is faster than the storm, it is possible to overtake it. In this case, the only action usually needed is to slow enough to let the storm pull ahead.

In all cases, one should be alert to changes in the direction of movement of the storm center, particularly in the area where the track normally curves toward the pole. If the storm maintains its direction and speed, the ship’s course should be maintained as the wind shifts.

If it becomes necessary for a vessel to heave to, the characteristics of the vessel should be considered. A power vessel is concerned primarily with damage by direct action of the sea. A good general rule is to heave to with head to the sea in the dangerous semicircle, or stern to the sea in the less dangerous semicircle. This will result in greatest amount of headway away from the storm center, and least amount of leeway toward it. If a vessel handles better with the sea astern or on the quarter, it may be placed in this position in the less dangerous semicircle or in the rear half of the dangerous semicircle, but never in the forward half of the dangerous semicircle. It has been reported that when the

wind reaches hurricane speed and the seas become confused, some ships ride out the storm best if the engines are stopped, and the vessel is left to seek its own position, or lie ahull. In this way, it is said, the ship rides with the storm instead of fighting against it.

In a sailing vessel attempting to avoid a storm center, one should steer courses as near as possible to those prescribed above for power vessels. However, if it becomes necessary for such a vessel to heave to, the wind is of greater concern than the sea. A good general rule always is to heave to on whichever tack permits the shifting wind to draw aft. In the Northern Hemisphere, this is the starboard tack in the dangerous semicircle, and the port tack in the less dangerous semicircle. In the Southern Hemisphere these are reversed.

While each storm requires its own analysis, and frequent or continual resurvey of the situation, the general rules for a steamer may be summarized as follows:

Northern Hemisphere

Right or dangerous semicircle: Bring the wind on the starboard bow (045˚ relative), hold course and make as much way as possible. If necessary, heave to with head to the sea.

Left or less dangerous semicircle: Bring the wind on the starboard quarter (135° relative), hold course and make as much way as possible. If necessary, heave to with stern to the sea.

On storm track, ahead of center: Bring the wind 2 points on the starboard quarter (about 160° relative), hold course and make as much way as possible. When well within the less dangerous semicircle, maneuver as indicated above.

On storm track, behind center: Avoid the center by the best practicable course, keeping in mind the tendency of tropical cyclones to curve northward and eastward.

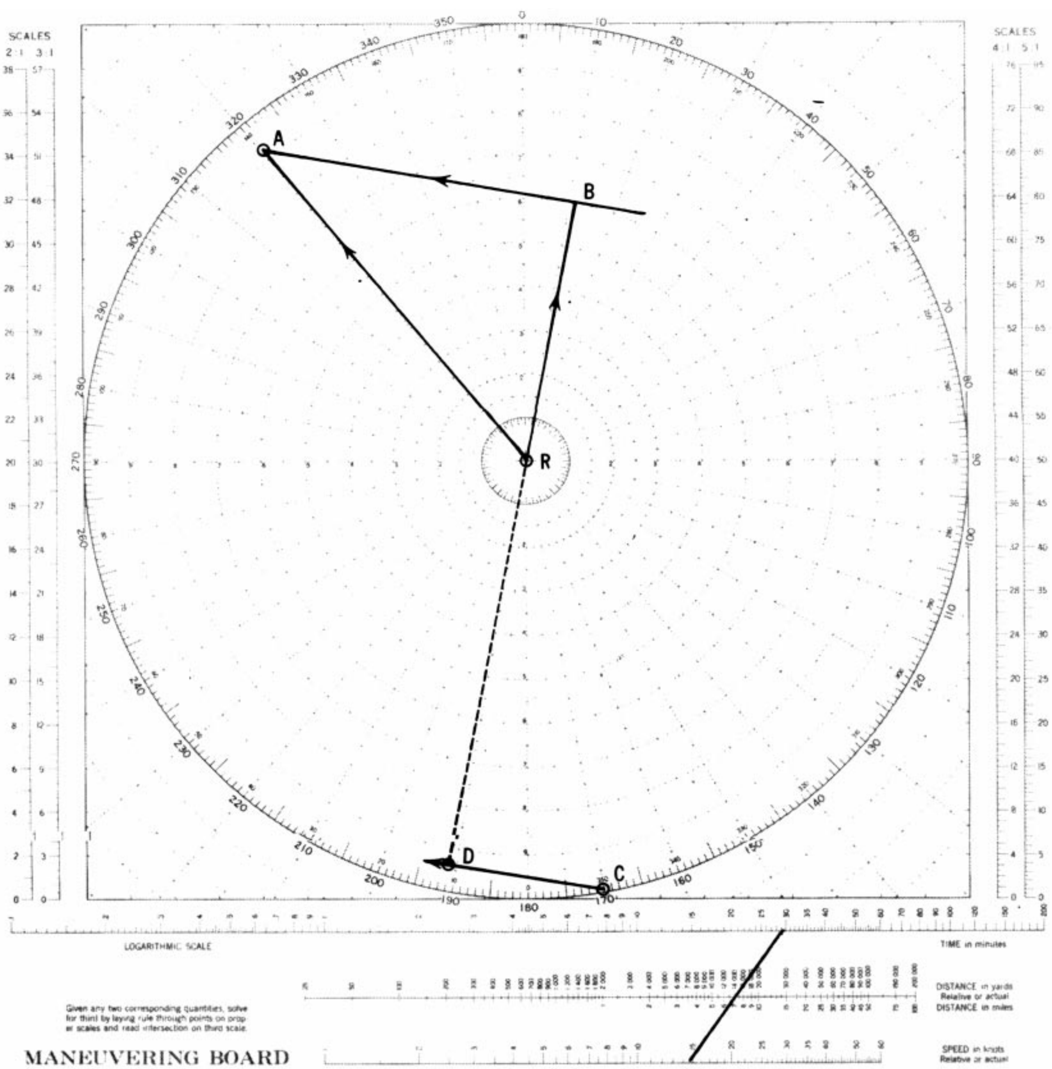


Figure 3611. Determining the course to avoid the storm center.

Southern Hemisphere

Left or dangerous semicircle: Bring the wind on the port bow (315° relative), hold course and make as much way as possible. If necessary, heave to with head to the sea.

Right or less dangerous semicircle: Bring the wind on the port quarter (225° relative), hold course and make as much way as possible. If necessary, heave to with stern to the sea.

On storm track, ahead of center: Bring the wind about 200° relative, hold course and make as much way as possible. When well within the less dangerous semicircle, maneuver as indicated above.

On storm track, behind center: Avoid the center by the best practicable course, keeping in mind the tendency of tropical cyclones to curve southward and eastward.

It is possible, particularly in temperate latitudes after the storm has recurved, that the dangerous semicircle is the left one in the Northern Hemisphere (right one in the Southern Hemisphere). This can occur if a large high lies north of the storm and causes a tightening of the pressure gradient in the region.

The *Typhoon Havens Handbook* for the Western Pacific and Indian Oceans is published by the Naval Oceanographic and Atmospheric Research Lab (NOARL) Monterey, California, as an aid to captains and commanding officers of ships in evaluating a typhoon situation, and to assist them in deciding whether to sortie, to evade, to remain in port, or to head for the shelter of a specific harbor.

CONSEQUENCES OF TROPICAL CYCLONES

3612. High Winds And Flooding

The high winds of a tropical cyclone inflict widespread damage when such a storm leaves the ocean and crosses land. Aids to navigation may be blown out of position or destroyed. Craft in harbors, often lifted by the storm surge, break moorings or drag anchor and are blown ashore and against obstructions. Ashore, trees are blown over, houses are damaged, power lines are blown down, etc. The greatest damage usually occurs in the dangerous semicircle a short distance from the center, where the strongest winds occur. As the storm continues on across land, its fury subsides faster than it would if it had remained over water.

Wind instruments are usually incapable of measuring the 175 to 200 knot winds of the more intense hurricanes; if the instrument holds up, often the supporting structure gives way. Doppler radar may be effective in determining wind speeds, but may also be blown away.

Wind gusts, which are usually 30 to 50 percent higher than sustained winds, add significantly to the destructiveness of the tropical cyclone. Many tropical cyclones that reach hurricane intensity develop winds of more than 90 knots sometime during their lives, but few develop winds of more than 130 knots.

Tropical cyclones have produced some of the world's heaviest rainfalls. While average amounts range from 6 to 10 inches, totals near 100 inches over a 4-day period have been observed. A 24-hour world's record of 73.62 inches fell at Reunion Island during a tropical cyclone in 1952. Forward movement of the storm and land topography have a considerable influence on rainfall totals. Torrential rains can occur when a storm moves against a mountain range; this is common in the Philippines and Japan, where even weak tropical depressions produce considerable rainfall. A 24-hour total of 46 inches was recorded in the Philippines during a typhoon in 1911. As hurricane Camille crossed southern Virginia's Blue Ridge Mountains in August of 1969, there was nearly 30 inches of rain in about 8 hours. This caused some of the most disastrous floods in the state's history.

Flooding is an extremely destructive by-product of the tropical cyclone's torrential rains. Whether an area will be flooded depends on the physical characteristics of the drainage basin, rate and accumulation of precipitation, and river stages at the time the rains begin. When heavy rains fall over flat terrain, the countryside may lie under water for a month or so, and while buildings, furnishings, and underground power lines may be damaged, there are usually few fatalities. In mountainous or hill country, disastrous floods develop rapidly and can cause a great loss of life.

There have been occasional reports in tropical cyclones of waves greater than 40 feet in height, and numerous reports in the 30- to 40-foot category. However, in tropical cyclones, strong winds rarely persist for a sufficiently long time or over a large enough area to permit enormous wave heights to develop. The direction and speed of the wind changes more rapidly in tropical cyclones than in extratropical storms. Thus, the maximum duration and fetch for any wind condition is often less in tropical cyclones than in extratropical storms, and the waves accompanying any given local wind conditions are generally not so high as those expected, with similar local wind conditions, in the high-latitude storms. In hurricane Camille, significant waves of 43 feet were recorded; an extreme wave height reached 72 feet.

Exceptional conditions may arise when waves of certain dimensions travel within the storm at a speed equal to the storm's speed, thus, in effect, extending the duration and fetch of the wave and significantly increasing its height. This occurs most often to the right of the track in the Northern Hemisphere (left of the track in the Southern Hemisphere). Another condition that may give rise to exceptional wave heights is the intersection of waves from

two or more distinct directions. This may lead to a zone of confused seas in which the heights of some waves will equal the sums of each individual wave train. This process can occur in any quadrant of the storm, so it should not be assumed that the highest waves will always be encountered to the right of the storm track in the Northern Hemisphere (left of the track in the Southern Hemisphere).

When these waves move beyond the influence of the generating winds, they become known as **swell**. They are recognized by their smooth, undulating form, in contrast to the steep, ragged crests of wind waves. This swell, particularly that generated by the right side of the storm, can travel a thousand miles or more and may produce tides 3 or 4 feet above normal along several hundred miles of coastline. It may also produce tremendous surf over offshore reefs which normally are calm.

When a tropical cyclone moves close to a coast, wind often causes a rapid rise in water level, and along with the falling pressure may produce a **storm surge**. This surge is usually confined to the right of the track in the Northern Hemisphere (left of the track in the Southern Hemisphere) and to a relatively small section of the coastline. It most often occurs with the approach of the storm, but in some cases, where a surge moves into a long channel, the effect may be delayed. Occasionally, the greatest rise in water is observed on the opposite side of the track, when northerly winds funnel into a partially landlocked harbor. The surge could be 3 feet or less, or it could be 20 feet or more, depending on the combination of factors involved.

There have been reports of a “hurricane wave,” described as a “wall of water,” which moves rapidly toward the coastline. Authenticated cases are rare, but some of the world’s greatest natural disasters have occurred as a result of this wave, which may be a rapidly rising and abnormally high storm surge. In India, such a disaster occurred in 1876, between Calcutta and Chittagong, and drowned more than 100,000 persons.

Along the coast, greater damage may be inflicted by water than by the wind. There are at least four sources of water damage. First, the unusually high seas generated by the storm winds pound against shore installations and craft in their way. Second, the continued blowing of the wind toward land causes the water level to increase perhaps 3 to 10 feet above its normal level. This **storm tide**, which may begin when the storm center is 500 miles or even farther from the shore, gradually increases until the storm passes. The highest storm tides are caused by a slow-moving tropical cyclone of large diameter, because both of these effects result in greater duration of wind in the same direction. The effect is greatest in a partly enclosed body of water, such as the Gulf of Mexico, where the concave coastline does not readily permit the escape of water. It is least on small islands, which present little obstruction to the flow of water. Third, the furious winds which blow around the wall of the eye create a ridge of water called a **storm wave**, which strikes the coast and often inflicts heavy damage. The effect is similar to that of a seismic sea wave, caused by an earthquake in the ocean floor. Both of these waves are popularly called **tidal waves**. Storm waves of 20 feet or more have occurred. About 3 or 4 feet of this wave is due to the decrease of atmospheric pressure, and the rest to winds. Like the damage caused by wind, damage due to high seas, the storm surge and tide, and the storm wave is greatest in the dangerous semicircle, near the center. The fourth source of water damage is the heavy rain that accompanies a tropical cyclone. This causes floods that add to the damage caused in other ways.

There have been many instances of tornadoes occurring within the circulation of tropical cyclones. Most of these have been associated with tropical cyclones of the North Atlantic Ocean and have occurred in the West Indies and along the gulf and Atlantic coasts of the United States. They are usually observed in the forward semicircle or along the advancing periphery of the storm. These tornadoes are usually short-lived and less intense than those that occur in the midwestern United States.

When proceeding along a shore recently visited by a tropical cyclone, a navigator should remember that time is required to restore aids to navigation which have been blown out of position or destroyed. In some instances the aid may remain but its light, sound apparatus, or radiobeacon may be inoperative. Landmarks may have been damaged or destroyed, and in some instances the coastline and hydrography may be changed.

CHAPTER 37

WEATHER OBSERVATIONS

BASICS OF WEATHER OBSERVATIONS

3700. Introduction

Weather forecasts are generally based upon information acquired by observations made at a large number of stations. Ashore, these stations are located so as to provide adequate coverage of the area of interest. Most observations at sea are made by mariners, wherever they happen to be. Since the number of observations at sea is small compared to the number ashore, marine observations are of great importance. Data recorded by designated vessels are sent by radio to weather centers ashore, where they are plotted, along with other observations, to provide data for drawing synoptic charts, which are used to make forecasts. Complete weather information gathered at sea by cooperating vessels is mailed to the appropriate meteorological services for use in the preparation of weather atlases and in marine climatological studies.

A special effort should be made to provide routine synoptic reports when transiting areas where few ships are available to report weather observations. This effort is particularly important in the tropics, where a vessel's synoptic weather report may be one of the first indications of a developing tropical cyclone. Even with satellite imagery, actual reports are needed to confirm suspicious patterns and provide actual temperature, pressure, and other measurements. Forecasts can be no better than the data received.

3701. Atmospheric Pressure

The sea of air surrounding the earth exerts a pressure of about 14.7 pounds per square inch on the surface of the earth. This **atmospheric pressure**, sometimes called **barometric pressure**, varies from place to place, and at the same place it varies over time.

Atmospheric pressure is one of the most basic elements of a meteorological observation. When the pressure at each station is plotted on a synoptic chart, lines of equal atmospheric pressure, called **isobars**, indicate the areas of high and low pressure. These are useful in making weather predictions, because certain types of weather are characteristic of each type of area, and the wind patterns over large areas can be deduced from the isobars.

Atmospheric pressure is measured with a **barometer**. A **mercurial barometer** measures pressure by balancing the weight of a column of air against that of a column of mercury. The **aneroid barometer** has a partly evacuated, thin metal cell which is compressed by atmospheric pressure; slight changes in air pressure cause the cell to expand or contract, while a system of levers magnifies and converts this motion to a reading on a gage or recorder.

Early mercurial barometers were calibrated to indicate the height, usually in inches or millimeters, of the column of mercury needed to balance the column of air above the point of measurement. While units of inches and millimeters are still widely used, many modern barometers are calibrated to indicate the centimeter-gram-second unit of pressure, the **millibar**, which is equal to 1,000 dynes per square centimeter. A dyne is the force required to accelerate a mass of one gram at the rate of one centimeter per second per second. A reading in any of the three units of measurement can be converted to the equivalent reading in either of the other units by means of tables, or the conversion factors given in the appendix. However, the pressure reading should always be reported in millibars.

3702. The Barometer

The **mercurial barometer** was invented by Evangelista Torricelli in 1643. In its simplest form it consists of a glass tube a little more than 30 inches in length and of uniform internal diameter. With one end closed, the tube is filled with mercury, and inverted into a cup of mercury. The mercury in the tube falls until the column is just supported by the pressure of the atmosphere on the open cup, leaving a vacuum at the upper end of the tube. The height of the column indicates atmospheric pressure, greater pressures supporting higher columns of mercury.

The mercurial barometer is subject to rapid variations in height, called **pumping**, due to pitch and roll of the vessel and temporary changes in atmospheric pressure in the vicinity of the barometer. Because of this, plus the care required in the reading the instrument, its bulkiness, and its vulnerability to physical damage, the mercurial barometer has been replaced at sea by the aneroid barometer.

3703. The Aneroid Barometer

The **aneroid barometer** measures the force exerted by atmospheric pressure on a partly evacuated, thin-metal element called a sylphon cell (aneroid capsule). A small spring is used, either internally or externally, to partly counteract the tendency of the atmospheric pressure to crush the cell.

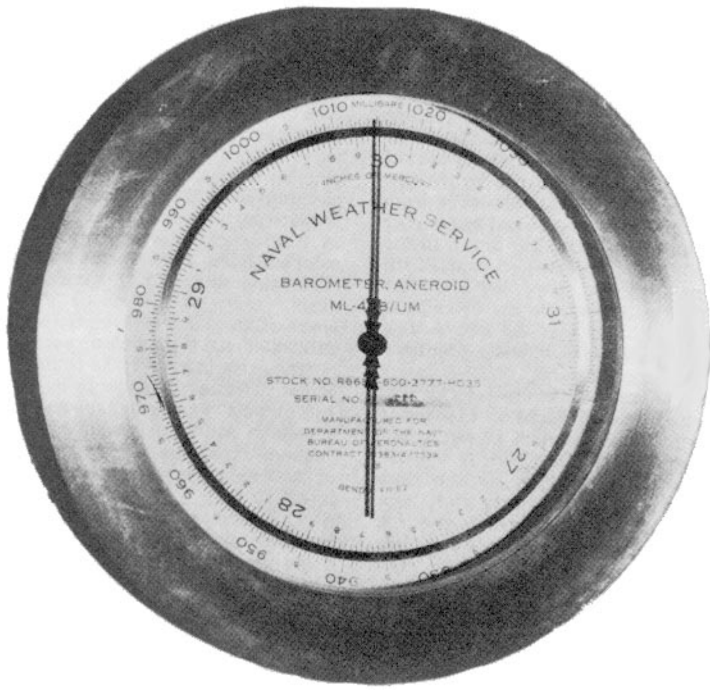


Figure 3703. An aneroid barometer.

Atmospheric pressure is indicated directly by a scale and a pointer connected to the cell by a combination of levers. The linkage provides considerable magnification of the slight motion of the cell, to permit readings to higher precision than could be obtained without it.

An aneroid barometer should be mounted permanently. Prior to installation, the barometer should be carefully set. U.S. ships of the Voluntary Observing Ship (VOS) program are set to sea level pressure. Other vessels may be set to station pressure and corrected for height as necessary. An adjustment screw is provided for this purpose. The error of the instrument is determined by comparison with a mercurial barometer or a standard precision aneroid barometer. If a qualified meteorologist is not available to make this adjustment, adjust by first removing only one-half the apparent error. The tap the case gently to assist the linkage to adjust itself, and repeat the adjustment. If the remaining error is not more than half a millibar (0.015 inch), no attempt should be made to remove it by further adjustment. Instead, a correction should be applied to the readings. The accuracy of this correction should be checked from time to time.

3704. The Barograph

The **barograph** is a recording barometer. In principle it is the same as a nonrecording aneroid barometer except that the pointer carries a pen at its outer end, and the scale is replaced by a slowly rotating cylinder around which a chart is wrapped. A clock mechanism inside the cylinder rotates the cylinder so that a continuous line is traced on the chart to indicate the pressure at any time.

The barograph is usually mounted on a shelf or desk in a room open to the atmosphere, in a location which minimizes the effect of the ship's vibration. Shock-absorbing material such as sponge rubber may be placed under the instrument to minimize vibration.

The pen should be checked and the inkwell filled each time the chart is changed.

A **marine microbarograph** is a precision barograph using greater magnification and an expanded chart. It is designed to maintain its precision through the conditions encountered aboard ship. Two sylphon cells are used, one mounted over the other in tandem. Minor fluctuations due to shocks or vibrations are eliminated by damping. Since oil-filled dashpots are used for this purpose, the instrument should never be inverted. The dashpots of the microbarograph should be kept filled with dashpot oil to within three-eighths inch of the top.

Ship motions are compensated by damping and spring loading which make it possible for the microbarograph to be tilted up to 22° without varying more than 0.3 millibars from true reading. Microbarographs have been almost entirely replaced by standard barographs.

Both instruments require checking from time to time to insure correct indication of pressure. The position of the pen is adjusted by a small knob provided for this purpose. The adjustment should be made in stages, eliminating half the apparent error, tapping the case to insure linkage adjustment to the new setting, and then repeating the process.

3705. Adjusting Barometer Readings

Atmospheric pressure as indicated by a barometer or barograph may be subject to several errors.

Instrument error: Inaccuracy due to imperfection or incorrect adjustment can be determined by comparison with a standard precision instrument. The National Weather Service provides a comparison service. In major U. S. ports a Port Meteorological Officer carries a portable precision aneroid barometer for barometer comparisons on board ships which participate in the Voluntary Observing Ship (VOS) program of the National Weather Service. The portable barometer is compared with station barometers before and after a ship visit. If a barometer is taken to a National Weather Service shore station, the comparison can be made there. The correct sea-level pressure can also be obtained by telephone. The shipboard barometer should be corrected for height, as explained below, before comparison with this value. If there is reason to believe that the barometer is in error, it should be compared with a standard, and if an error is found, the barometer should be adjusted to the correct reading, or a correction applied to all readings.

Height error: The atmospheric pressure reading at the height of the barometer is called the **station pressure** and is subject to a height correction in order to make it a sea level pressure reading. Isobars adequately reflect wind conditions and geographic distribution of pressure only when they are drawn for pressure at constant height (or the varying height at which a constant pressure exists). On synoptic charts it is customary to show the equivalent pressure at sea level, called **sea level pressure**. This is found by applying a correction to station pressure. The correction depends upon the height of the barometer and the average temperature of the air between this height and the surface. The outside air temperature taken aboard ship is sufficiently accurate for this purpose. This is an important correction which should be applied to all readings of any type barometer. See Table 31 for this correction.

Gravity error: Mercurial barometers are calibrated for standard sea-level gravity at latitude 45°32'40". If the gravity differs from this amount, an error is introduced. The correction to be applied to readings at various latitudes is given in Table 32. This correction does not apply to readings of an aneroid barometer or microbarograph. Gravity also changes with height above sea level, but the effect is negligible for the first few hundred feet, and so is not needed for readings taken aboard ship. See Table 32 for this correction.

Temperature error: Barometers are calibrated at a standard temperature of 32°F. The liquid of a mercurial barometer expands as the temperature of the mercury rises, and contracts as it decreases. The correction to adjust the reading of the instrument to the true value is given in Table 33. This correction is applied to readings of mercurial barometers only. Modern aneroid barometers are compensated for temperature changes by the use of different metals having unequal coefficients of linear expansion.

3706. Temperature

Temperature is a measure of heat energy, measured in degrees. Several different temperature scales are in use.

On the **Fahrenheit (F)** scale pure water freezes at 32° and boils at 212°.

On the **Celsius (C)** scale commonly used with the metric system, the freezing point of pure water is 0° and the boiling point is 100°. This scale, has been known by various names in different countries. In the United States it was formerly called the centigrade scale. The Ninth General Conference of Weights and Measures, held in France in 1948, adopted the name Celsius to be consistent with the naming of other temperature scales after their inventors, and to avoid the use of different names in different countries. On the original Celsius scale, invented in 1742 by a Swedish astronomer named Anders Celsius, numbering was the reverse of the modern scale, 0° representing the boiling point of water, and 100° its freezing point.

Absolute zero is considered to be the lowest possible temperature, at which there is no molecular motion and a body has no heat. For some purposes, it is convenient to express temperature by a scale at which 0° is absolute zero. This is called **absolute temperature**. If Fahrenheit degrees are used, it may be called **Rankine (R)** temperature; and if Celsius, **Kelvin (K)** temperature. The Kelvin scale is more widely used than the Rankine. Absolute zero is –459.69°F or –273.16°C.

Temperature of one scale can be easily converted to another because of the linear mathematical relationship between them. Note that the sequence of calculation is slightly different; algebraic rules must be followed.

$$C = \frac{5}{9}(F - 32), \text{ or } \qquad C = \frac{F - 32}{1.8}$$

$$F = \frac{9}{5}C + 32, \text{ or } \qquad F = 1.8C + 32$$

$$K = C + 273.16$$

$$R = F + 459.69$$

A temperature of –40° is the same by either the Celsius or Fahrenheit scale. Similar formulas can be made for conversion of other temperature scale readings. The Conversion Table for Thermometer Scales (Table 29) gives the equivalent values of Fahrenheit, Celsius, and Kelvin temperatures.

The intensity or degree of heat (temperature) should not be confused with the amount of heat. If the temperature of air or some other substance is to be increased (the substance made hotter) by a given number of degrees, the amount of heat that must be added is dependent upon the amount of the substance to be heated. Also, equal amounts of different substances require the addition of unequal amounts of heat to effect an equal increase in temperature because of their difference of specific heat. Units used for measurement of amount of heat are the **British thermal unit (BTU)**, the amount of heat needed to

raise the temperature of 1 pound of water 1° Fahrenheit; and the **calorie**, the amount of heat needed to raise the temperature of 1 gram of water 1° Celsius.

3707. Temperature Measurement

Temperature is measured with a **thermometer**. Most thermometers are based upon the principle that materials expand with an increase of temperature, and contract as temperature decreases. In its most usual form a thermometer consists of a bulb filled with mercury and connected to a tube of very small cross-sectional area. The mercury only partly fills the tube. In the remainder is a vacuum. Air is driven out by boiling the mercury, and the top of the tube is then sealed. As the mercury expands or contracts with changing temperature, the length of the mercury column in the tube changes.

Sea surface temperature observations are used in the forecasting of fog and furnish important information about the development and movement of tropical cyclones. Commercial fishermen are interested in the sea surface temperature as an aid in locating certain species of fish. There are several methods of determining seawater temperature. These include engine room intake readings, condenser intake readings, thermistor probes attached to the hull, and readings from buckets recovered from over the side. Although the condenser intake method is not a true measure of surface water temperature, the error is generally small.

If the surface temperature is desired, a sample should be obtained by bucket, preferably a canvas bucket, from a forward position well clear of any discharge lines. The sample should be taken immediately to a place where it is sheltered from wind and sun. The water should then be stirred with the thermometer, keeping the bulb submerged, until a constant reading is obtained.

A considerable variation in sea surface temperature can be experienced in a relatively short distance of travel. This is especially true when crossing major ocean currents such as the Gulf Stream and the Kuroshio Current. Significant variations also occur where large quantities of freshwater are discharged from rivers. A clever navigator will note these changes as in indication of when to allow for set and drift in dead reckoning.

3708. Humidity

Humidity is a measure of the atmosphere's water vapor content. **Relative humidity** is the ratio, stated as a percentage, of the pressure of water vapor present in the atmosphere to the saturation vapor pressure at the same temperature.

As air temperature decreases, the relative humidity increases. At some point, saturation takes place, and any further cooling results in condensation of some of the moisture. The temperature at which this occurs is called the dew point, and the moisture deposited upon objects is called dew if it forms in the liquid state, or frost if it forms in the frozen state.

The same process causes moisture to form on the outside of a container of cold liquid, the liquid cooling the air in the immediate vicinity of the container until it reaches the dew point. When moisture is deposited on man-made objects, it is usually called **sweat**. It occurs whenever the temperature of a surface is lower than the dew point of air in contact with it. It is of particular concern to the mariner because of its effect upon his instruments, and possible damage to his ship or its cargo. Lenses of optical instruments may sweat, usually with such small droplets that the surface has a "frosted" appearance. When this occurs, the instrument is said to "fog" or "fog up," and is useless until the moisture is removed. Damage is often caused by corrosion or direct water damage when pipes sweat and drip, or when the inside of the shell plates of a vessel sweat. Cargo may sweat if it is cooler than the dew point of the air.

Clouds and fog form from condensation of water on minute particles of dust, salt, and other material in the air. Each particle forms a nucleus around which a droplet of water forms. If air is completely free from solid particles on which water vapor may condense, the extra moisture remains in the vapor state, and the air is said to be **supersaturated**.

Relative humidity and dew point are measured with a **hygrometer**. The most common type, called a **psychrometer**, consists of two thermometers mounted together on a single strip of material. One of the thermometers is mounted a little lower than the other, and has its bulb covered with muslin. When the muslin covering is thoroughly moistened and the thermometer well ventilated, evaporation cools the bulb of the thermometer, causing it to indicate a lower reading than the other. A **sling psychrometer** is ventilated by whirling the thermometers. The difference between the dry-bulb and wet-bulb temperatures is used to enter **psychrometric tables** (Table 35 and Table 36) to find the relative humidity and dew point. If the wet-bulb temperature is above freezing, reasonably accurate results can be obtained by a psychrometer consisting of dry- and wet-bulb thermometers mounted so that air can circulate freely around them without special ventilation. This type of installation is common aboard ship.

Example: *The dry-bulb temperature is 65°F, and the wet-bulb temperature is 61°F.*

Required: *(1) Relative humidity, (2) dew point.*

Solution: *The difference between readings is 4°. Entering Table 35 with this value, and a dry-bulb temperature of 65°, the relative humidity is found to be 80 percent. From Table 36 the dew point is 58°.*

Answers: *(1) Relative humidity 80 percent, (2) dew point 58°.*

Also in use aboard many ships is the **electric psychrometer**. This is a hand held, battery operated instrument with two mercury thermometers for obtaining dry- and wet-bulb temperature readings. It consists of a plastic housing that holds the thermometers, batteries, motor, and fan.

3709. Wind Measurement

Wind measurement consists of determination of the direction and speed of the wind. Direction is measured by a **wind vane**, and speed by an **anemometer**.

Several types of wind speed and direction sensors are available, using vanes to indicate wind direction and rotating cups or propellers for speed sensing. Many ships have reliable wind instruments installed, and inexpensive wind instruments are available for even the smallest yacht. If no anemometer is available, wind speed can be estimated by its effect upon the sea and nearby objects. The direction can be computed accurately, even on a fast moving vessel, by maneuvering board or Table 30.

3710. True And Apparent Wind

An observer aboard a vessel proceeding through still air experiences an apparent wind which is from dead ahead and has an apparent speed equal to the speed of the vessel. Thus, if the actual or true wind is zero and the speed of the vessel is 10 knots, the apparent wind is from dead ahead at 10 knots. If the true wind is from dead ahead at 15 knots, and the speed of the vessel is 10 knots, the apparent wind is 15 + 10 = 25 knots from dead ahead. If the vessel reverses course, the apparent wind is 15 – 10 = 5 knots, from dead astern.

The **apparent wind** is the vector sum of the true wind and the *reciprocal* of the vessel's course and speed vector. Since wind vanes and anemometers measure apparent wind, the usual problem aboard a vessel equipped with an anemometer is to convert apparent wind to true wind. There are several ways of doing this. Perhaps the simplest is by the graphical solution illustrated in the following example:

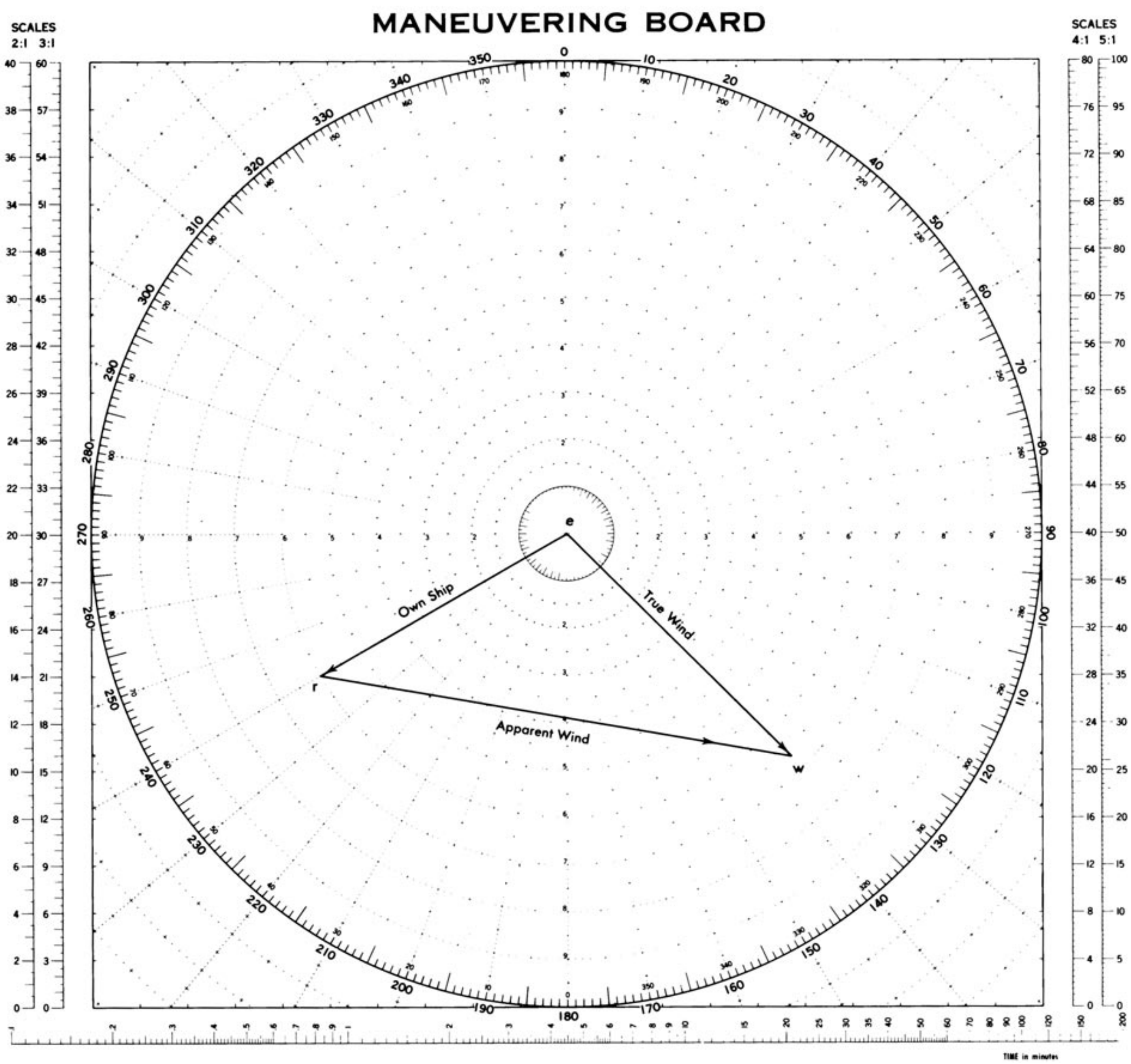


Figure 3710. Finding true wind by Maneuvering Board.

Example 1: *A ship is proceeding on course 240° at a speed of 18 knots. The apparent wind is from 040° relative at 30 knots.*

Required: *The direction and speed of the true wind.*

Solution: *First starting from the center of a maneuvering board, plot the ship's vector er, at 240°, length 18 knots (using the 3–1 scale). Next plot the relative wind's vector from r, in a direction of 100° (the reciprocal of 280°) length 30 knots. The true wind is from the center to the end of this vector or line ew.*

Alternatively, you can plot the ship's vector from the center, then plot the relative wind's vector toward the center, and see the true wind's vector from the end of this line to the end of the ship's vector. Use parallel rulers to transfer the wind vector to the center for an accurate reading.

Answer: *True wind is from 315° at 20 knots.*

On a moving ship, the direction of the true wind is always on the same side and aft of the direction of the apparent wind. The faster the ship moves, the more the apparent wind draws ahead of the true wind.

Solution can also be made without plotting, in the following manner: On a maneuvering board, label the circles 5, 10, 15, 20, etc., from the center, and draw vertical lines tangent to these circles. Cut out the 5:1 scale and discard that part having graduations greater than the maximum speed of the vessel. Keep this sheet for all solutions. (For durability, the two parts can be mounted on cardboard or other suitable material.) To find true wind, spot in point 1 by eye. Place the zero of the 5:1 scale on this point and align the scale (inverted) using the vertical lines. Locate point 2 at the speed of the vessel as indicated on the 5:1 scale. It is always vertically below point 1. Read the relative direction and the speed of the true wind, using eye interpolation if needed.

A tabular solution can be made using Table 30, Direction and Speed of True Wind in Units of Ship's Speed. The entering values for this table are the apparent wind speed in units of ship's speed, and the difference between the heading and the apparent wind direction. The values taken from the table are the relative direction (right or left) of the true wind, and the speed of the true wind in units of ship's speed. If a vessel is proceeding at 12 knots, 6 knots constitutes one-half (0.5) unit, 12 knots one unit, 18 knots 1.5 units, 24 knots two units, etc.

Example 2: *A ship is proceeding on course 270° at a speed of 10 knots. The apparent wind is from 10° off the port bow, speed 30 knots.*

Required: *The relative direction, true direction, and speed of the true wind by table.*

Solution: *The apparent wind speed is*

$$\frac{30}{10} = 3.0 \text{ ships speed units}$$

Enter Table 30 with 3.0 and 10° and find the relative direction of the true wind to be 15° off the port bow (345° relative), and the speed to be 2.02 times the ship's speed, or 20 knots, approximately. The true direction is 345° + 270° = 255°.

Answers: *True wind from 345° relative = 255° true, at 20 knots.*

By variations of this problem, one can find the apparent wind from the true wind, the course or speed required to produce an apparent wind from a given direction or speed, or the course and speed to produce an apparent wind of a given speed from a given direction. Such problems often arise in aircraft carrier operations and in some rescue situations. See *Pub. 217, Maneuvering Board Manual*, for more detailed information.

When wind speed and direction are determined by the appearance of the sea, the result is true speed and direction. Waves move in the same direction as the generating wind, and are not deflected by earth's rotation. If a wind vane is used, the direction of the apparent wind thus determined can be used with the speed of the true wind to determine the direction of the true wind by vector diagram.

WIND AND WAVES

3711. Effects Of Wind On The Sea

There is a direct relationship between the speed of the wind and the state of the sea. This is useful in predicting the sea conditions to be anticipated when future wind speed forecasts are available. It can also be used to estimate the speed of the wind, which may be necessary when an anemometer is not available.

Wind speeds are usually grouped in accordance with the Beaufort scale, named after Admiral Sir Francis Beaufort (1774-1857), who devised it in 1806. As adopted in 1838, Beaufort numbers ranged from 0 (calm) to 12 (hurricane). The Beaufort wind scale and sea state photographs which are at the end of this chapter can be used to estimate wind speed.

These pictures *(courtesy of Environment Canada)* present the results of a project carried out on board the Canadian Ocean Weather Ships VANCOUVER and QUADRA at Ocean Weather Station PAPA (50°N., 145°W), between April 1976 and May 1981. The aim of the project was to collect color photographs of the sea surface as it appears under the influence of the various ranges of wind speed, as defined by The Beaufort Scale of Wind Force. The photographs represent as closely as possible steady-state sea conditions over many hours for each Beau-

fort wind force, except Force 12, for which no photographs are available. They were taken from heights ranging from 12-17 meters above the sea surface; anemometer height was 28 meters.

3712. Estimating The Wind At Sea

Observers on board ships at sea usually determine the speed of the wind by estimating Beaufort Force, as merchant ships may not be equipped with wind measuring instruments. Through experience, ships' officers have developed various methods of estimating this force. The effect of the wind on the observer himself, the ship's rigging, flags, etc., is used as a guide, but estimates based on these indications give the relative wind which must be corrected for the motion of the ship before an estimate of the true wind speed can be obtained.

The most common method involves the appearance of the sea surface. The state of the sea disturbance, i.e. the dimensions of the waves, the presence of white caps, foam, or spray, depends principally on three factors:

1. **The wind speed**. The higher the speed of the wind, the greater is the sea disturbance.
2. **The wind's duration**. At any point on the sea, the disturbance will increase the longer the wind blows at a given speed, until a maximum state of disturbance is reached.
3. **The fetch**. This is the length of the stretch of water over which the wind acts on the sea surface from the same direction.

For a given wind speed and duration, the longer the fetch, the greater is the sea disturbance. If the fetch is short, such as a few miles, the disturbance will be relatively small no matter how great the wind speed is or how long it has been blowing.

There are other factors which can modify the appearance of the sea surface caused by wind alone. These are strong currents, shallow water, swell, precipitation, ice, and wind shifts. Their effects will be described later.

A wind of a given Beaufort Force will, therefore, produce a characteristic appearance of the sea surface provided that it has been blowing for a sufficient length of time, and over a sufficiently long fetch.

In practice, the mariner observes the sea surface, noting the size of the waves, the white caps, spindrift, etc., and then finds the criterion which best describes the sea surface as he saw it. This criterion is associated with a Beaufort number, for which a corresponding mean wind speed and range in knots are given. Since meteorological reports require that wind speeds be reported in knots, the mean speed for the Beaufort number may be reported, or an experienced observer may judge that the sea disturbance is such that a higher or lower speed within the range for the force is more accurate.

This method should be used with caution. The sea conditions described for each Beaufort Force are "steady-state" conditions; i.e. the conditions which result when the wind has been blowing for a relatively long time, and over a great stretch of water. At any particular time at sea, though, the duration of the wind or the fetch, or both, may not have been great enough to produce these "steady-state" conditions. When a high wind springs up suddenly after previously calm or near calm conditions, it will require some hours, depending on the strength of the wind, to generate waves of maximum height. The height of the waves increases rapidly in the first few hours after the commencement of the blow, but increases at a much slower rate later on.

At the beginning of the fetch (such as at a coastline when the wind is offshore) after the wind has been blowing

Beaufort force of wind.	Theoretical maximum wave height (ft) unlimited duration and fetch.	Duration of winds, (hours), with unlimited fetch, to produce percent of maximum wave height indicated.			Fetch (nautical miles), with unlimited duration of blow, to produce percent of maximum wave height indicated.		
		50%	75%	90%	50%	75%	90%
3	2	1.5	5	8	3	13	25
5	8	3.5	8	12	10	30	60
7	20	5.5	12	21	22	75	150
9	40	7	16	25	55	150	280
11	70	9	19	32	85	200	450

Table 3712. Duration of winds and length of fetches required for various wind forces.

for a long time, the waves are quite small near shore, and increase in height rapidly over the first 50 miles or so of the fetch. Farther offshore, the rate of increase in height with distance slows down, and after 500 miles or so from the beginning of the fetch, there is little or no increase in height.

Table 3712 illustrates the duration of winds and the length of fetches required for various wind forces to build seas to 50 percent, 75 percent, and 90 percent of their theoretical maximum heights.

The theoretical maximum wave heights represent the average heights of the highest third of the waves, as these waves are most significant.

It will be seen that winds of force 5 or less can build seas to 90 percent of their maximum height, in less than 12 hours, provided the fetch is long enough. Higher winds require a much greater time-force 11 winds requiring 32 hours to build waves to 90 percent of their maximum height. The times given in Table 3712 represent those required to build waves starting from initially calm sea conditions. If waves are already present at the onset of the blow, the times would be somewhat less depending on the initial wave heights and their direction relative to the direction of the wind which has sprung up.

The first consideration when using the sea criterion to estimate wind speed, therefore, is to decide whether the wind has been blowing long enough from the same direction to produce a steady state sea condition. If not, then it is possible that the wind speed may be underestimated.

Experience has shown that the appearance of white-caps, foam, spindrift, etc., reaches a steady state condition before the height of the waves attain their maximum value. It is a safe assumption that the appearance of the sea (such as white-caps, etc.) will reach a steady state in the time required to build the waves to 50-75 percent of their maximum height. Thus, from Table 3712, it is seen that a force 5 wind could require 8 hours at most to produce a characteristic appearance of the sea surface.

A second consideration, when using the sea criterion, is the length of the fetch over which the wind has been blowing to produce the present state of the sea. On the open sea, unless the mariner has the latest synoptic weather map available, the length of the fetch will not be known. It will be seen from Table 3712, though, that only relatively short fetches are required for the lower wind forces to generate their characteristic seas. On the open sea, the fetches associated with most storms and other weather systems are usually long enough so that even winds up to force 9 can build seas up to 90 percent or more of their maximum height, providing the wind blows from the same direction long enough.

When navigating close to a coast, or in restricted waters, however, it may be necessary to make allowances for the shorter stretches of water over which the wind blows. For example, referring to Table 3712, if the ship is 22 miles from a coast, and an offshore wind with an actual speed of force 7 is blowing, the waves at the ship will never attain more than 50 percent of their maximum height for this speed no matter how long the wind blows. Hence, if the sea criterion were used under these conditions without consideration of the short fetch, the wind speed would be underestimated. With an offshore wind, the sea criterion may be used with confidence if the distance to the coast is greater than the values given in the extreme right-hand column of Table 3712; again, provided that the wind has been blowing offshore for a sufficient length of time.

3713. Special Wind Effects

Tidal and Other Currents: A wind blowing against a tide or strong current causes a greater sea disturbance than normal, which may result in an overestimate of the wind speed. On the other hand, a wind blowing in the same direction as a tide or strong current causes less sea disturbance than normal, and may result in an underestimate of the wind speed.

Shallow Water: Waves running into shallow water increase in steepness, and hence, their tendency to break. With an onshore wind there will, therefore, be more white-caps over the shallow waters than over the deeper water farther offshore. It is only over relatively deep water that the sea criterion can be used with confidence.

Swell: Swell is the name given to waves, generally of considerable length, which were raised in some distant area by winds blowing there, and which have moved into the vicinity of the ship; or to waves raised nearby and which continue to advance after the wind at the ship has abated or changed direction. The direction of swell waves is usually different from the direction of the wind and the sea waves. Swell waves are not considered when estimating wind speed and direction. Only those waves raised by the wind blowing at the time are of any significance. The wind-driven waves show a greater tendency to break when superimposed on the crests of swell, and hence, more whitecaps may be formed than if the swell were absent. Under these conditions, the use of the sea criterion may result in a slight overestimate of the wind speed.

Precipitation: Heavy rain has a damping or smoothing effect on the sea surface which must be mechanical in character. Since the sea surface will therefore appear less disturbed than would be the case without the rain, the wind speed may be underestimated unless the smoothing effect is taken into account.

Ice: Even small concentrations of ice floating on the sea surface will dampen waves considerably, and concentrations greater than about seven-tenths average will eliminate waves altogether. Young sea ice, which in the early stages of formation has a thick soupy consistency, and later takes on a rubbery appearance, is very effective in dampening waves. Consequently, the sea criterion cannot be used with any degree of confidence when sea ice is present. In higher latitudes, the presence of an ice field some distance to windward of the ship may be suspected if, when the ship is not close to any coast, the wind is relatively strong but the seas abnormally underdeveloped. The edge of the ice field acts like a coastline, and the short fetch between the ice and the

ship is not sufficient for the wind to fully develop the seas.

Wind Shifts: Following a rapid change in the direction of the wind, as occurs at the passage of a cold front, the new wind will flatten out to a great extent the waves which were present before the wind shift. This happens because the direction of the wind after the shift may differ by 90° or more from the direction of the waves, which does not change. Hence, the wind may oppose the progress of the waves and dampen them out quickly. At the same time, the new wind begins to generate its own waves on top of this dissipating swell, and it is not long before the cross pattern of waves gives the sea a "choppy" or confused appearance. It is during the first few hours following the wind shift that the appearance of the sea surface may not provide a reliable indication of wind speed. The wind is normally stronger than the sea would indicate, as old waves are being flattened out, and new waves are beginning to be developed.

Night Observations: On a dark night, when it is impossible to see the sea clearly, the observer may estimate the apparent wind from its effect on the ship's rigging, flags, etc., or simply the "feel" of the wind.

CLOUDS

3714. Cloud Formation

Clouds consist of innumerable tiny droplets of water, or ice crystals, formed by condensation of water vapor around microscopic particles in the air. **Fog** is a cloud in contact with the surface of the earth.

The shape, size, height, thickness, and nature of a cloud depend upon the conditions under which it is formed. Therefore, clouds are indicators of various processes occurring in the atmosphere. The ability to recognize different types, and a knowledge of the conditions associated with them, are useful in predicting future weather.

Although the variety of clouds is virtually endless, they may be classified according to general type. Clouds are grouped generally into three "families" according to common characteristics. **High clouds** have a mean lower level above 20,000 feet. They are composed principally of ice crystals. **Middle clouds** have a mean level between 6,500 and 20,000 feet. They are composed largely of water droplets, although the higher ones have a tendency toward ice particles. **Low clouds** have a mean lower level of less than 6,500 feet. These clouds are composed entirely of water droplets.

Within these 3 families are 10 principal cloud types. The names of these are composed of various combinations and forms of the following basic words, all from Latin:

Cirrus, meaning "curl, lock, or tuft of hair."
Cumulus, meaning "heap, a pile, an accumulation."
Stratus, meaning "spread out, flatten, cover with a layer."
Alto, meaning "high, upper air."
Nimbus, meaning "rainy cloud."

Individual cloud types recognize certain characteristics, variations, or combinations of these. The 10 principal cloud types and their commonly used symbols are:

3715. High Clouds

Cirrus (Ci) are detached high clouds of delicate and fibrous appearance, without shading, generally white in color, and often of a silky appearance (Figure 3715a and Figure 3715d). Their fibrous and feathery appearance is caused by their composition of ice crystals. Cirrus appear in varied forms such as isolated tufts; long, thin lines across the sky; branching, feather-like plumes; curved wisps which may end in tufts, and other shapes. These clouds may be arranged in parallel bands which cross the sky in great circles, and appear to converge toward a point on the horizon. This may indicate the general direction of a low pressure area. Cirrus may be brilliantly colored at sunrise and sunset. Because of their height, they become illuminated before other clouds in the morning, and remain lighted after others at sunset. Cirrus are generally associated with fair weather, but if they are followed by lower and thicker clouds, they are often the forerunner of rain or snow.

Cirrocumulus (Cc) are high clouds composed of small white flakes or scales, or of very small globular masses, usually without shadows and arranged in groups of lines, or more often in ripples resembling sand on the seashore (Figure 3715b). One form of cirrocumulus is popularly known as "mackerel sky" because the pattern resembles the scales on the back of a mackerel. Like cirrus, cirrocumulus are composed of ice crystals and are generally associated with fair weather, but may precede a storm if they thicken and lower. They may turn gray and appear hard before thickening.

Cirrostratus (Cs) are thin, whitish, high clouds (Fig. 3715c) sometimes covering the sky completely and giving it a milky appearance and at other times presenting, more or less distinctly, a formation like a tangled web. The thin veil is not sufficiently dense to blur the outline of sun or moon. However, the ice crystals of which the cloud is composed refract the light passing through to form halos with the sun or moon at the center. Figure 3715d shows cirrus thickening and changing into cirrostratus. In this form it is popularly known as "mares' tails." If it continues to thicken and lower, the ice crystals melting to form water droplets, the cloud formation is known as altostratus. When this occurs, rain may normally be expected within 24 hours. The more brush-like the cirrus when the sky appears as in Figure 3715d, the stronger wind at the level of the cloud.

Figure 3715a. Cirrus.

Figure 3715b. Cirrocumulus.

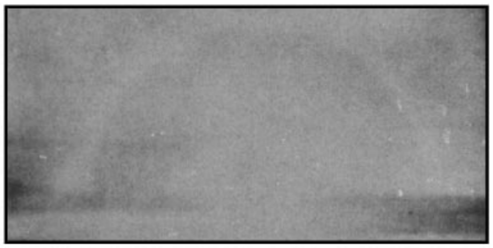


Figure 3715c. Cirrostratus.

Figure 3715d. Cirrus and cirrostratus.

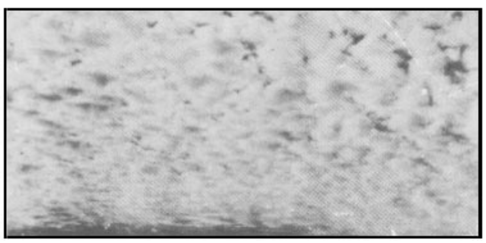


Figure 3716a. Altocumulus in patches.

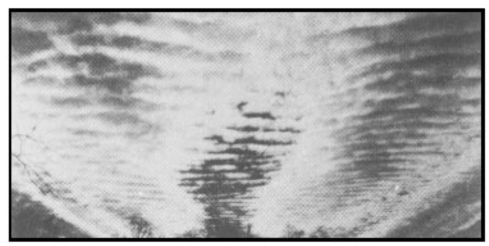


Figure 3716b. Altocumulus in bands.

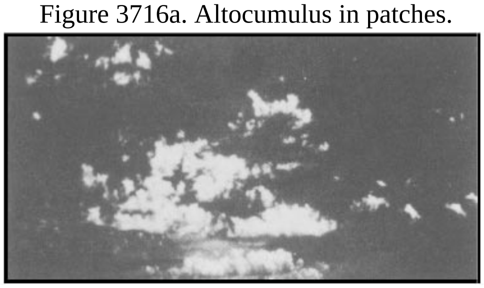


Figure 3716c. Turreted altocumulus.

Figure 3716d. Altostratus.

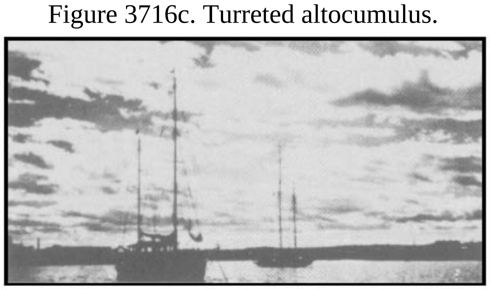


Figure 3717a. Stratocumulus.

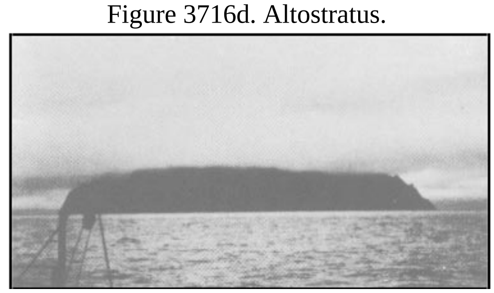


Figure 3717b. Stratus.

Figure 3717c. Cumulus.

Figure 3717d. Cumulonimbus.

3716. Middle Clouds

Altocumulus (Ac) are middle level clouds consisting of a layer of large, ball-like masses that tend to merge together. The balls or patches may vary in thickness and color from dazzling white to dark gray, but they are more or less regularly arranged. They may appear as distinct patches (Figure 3716a) similar to cirrocumulus, but can be distinguished by having individual patches which are generally larger, showing distinct shadows in some places. They are often mistaken for stratocumulus. If altocumulus thickens and lowers, it may produce thundery weather and showers, but it does not bring prolonged bad weather. Sometimes the patches merge to form a series of big rolls resembling ocean waves, with streaks of blue sky between (Figure 3716b). Because of perspective, the rolls appear to run together near the horizon. These regular parallel bands differ from cirrocumulus because they occur in larger masses with shadows. Altocumulus move in the direction of the short dimension of the rolls, like ocean waves. Sometimes altocumulus appear briefly in the form shown in Figure 3716c, usually before a thunderstorm. They are generally arranged in a line with a flat horizontal base, giving the impression of turrets on a castle. The turreted tops may look like miniature cumulus and possess considerable depth and great length. These clouds usually indicate a change to chaotic, thundery skies.

Altostratus (As) are middle clouds having the appearance of a grayish or bluish, fibrous veil or sheet (Figure 3716d). The sun or moon, when seen through these clouds, appears as if it were shining through ground glass, with a corona around it. Halos are not formed. If these clouds thicken and lower, or if low, ragged “scud” or rain clouds (nimbostratus) form below them, continuous rain or snow may be expected within a few hours.

3717. Low Clouds

Stratocumulus (Sc) are low clouds appearing as soft, gray, roll-shaped masses (Figure 3717a). They may be shaped in long, parallel rolls similar to altocumulus, moving forward with the wind. The motion is in the direction of their short dimension, like ocean waves. These clouds, which vary greatly in altitude, are the final product of the characteristic daily change taking place in cumulus clouds. They are usually followed by clear skies during the night.

Stratus (St) is a low cloud in a uniform layer (Figure 3717b) resembling fog. Often the base is not more than 1,000 feet high. A veil of thin stratus gives the sky a hazy appearance. Stratus is often quite thick, permitting so little sunlight to penetrate that it appears dark to an observer below. From above, it is white. Light mist may descend from stratus. Strong wind sometimes breaks stratus into shreds called “fractostratus.”

Nimbostratus (Ns) is a low, dark, shapeless cloud layer, usually nearly uniform, but sometimes with ragged, wet-looking bases. Nimbostratus is the typical rain cloud. The precipitation which falls from this cloud is steady or intermittent, but not showery.

Cumulus (Cu) are dense clouds with vertical development formed by rising air which is cooled as it reaches greater heights. See Figure 3717c. They have a horizontal base and dome-shaped upper surface, with protuberances extending above the dome. Cumulus appear in small patches, and never cover the entire sky. When the vertical development is not great, the clouds appear in patches resembling tufts of cotton or wool, being popularly called “woolpack” clouds. The horizontal bases of such clouds may not be noticeable. These are called “fair weather” cumulus because they commonly accompany good weather. However, they may merge with altocumulus, or may grow to cumulonimbus before a thunderstorm. Since cumulus are formed by updrafts, they are accompanied by turbulence, causing “bumpiness” in the air. The extent of turbulence is proportional to the vertical extent of the clouds. Cumulus are marked by strong contrasts of light and dark.

Cumulonimbus (Cb) is a massive cloud with great vertical development, rising in mountainous towers to great heights (Figure 3717d). The upper part consists of ice crystals, and often spreads out in the shape of an anvil which may be seen at such distances that the base may be below the horizon. Cumulonimbus often produces showers of rain, snow, or hail, frequently accompanied by lightning and thunder. Because of this, the cloud is often popularly called a “thundercloud” or “thunderhead.” The base is horizontal, but as showers occur it lowers and becomes ragged.

3718. Cloud Height Measurement

At sea, cloud heights are often determined by estimate. This is a difficult task, particularly at night.

The height of the base of clouds formed by vertical development (any form of cumulus), if formed in air that has risen from the surface of the earth, can be determined by psychrometer, because the height to which the air must rise before condensation takes place is proportional to the difference between surface air temperature and the dew point. At sea, this difference multiplied by 126.3 gives the height in meters. That is, for every degree difference between surface air temperature and the dew point, the air must rise 126.3 meters before condensation will take place. Thus, if the dry-bulb temperature is 26.8°C, and the wet-bulb temperature is 25.0°C, the dew point is 24°C, or 2.8°C lower than the surface air temperature. The height of the cloud base is $2.8 \times 126.3 = 354$ meters.

OTHER OBSERVATIONS

3719. Visibility Measurement

Visibility is the horizontal distance at which prominent objects can be seen and identified by the unaided eye. It is usually measured directly by the human eye. Ashore, the distances of various buildings, trees, lights, and other objects can be used as a guide in estimating the visibility. At sea, however, such an estimate is difficult to make with accuracy. Other ships and the horizon may be of some assistance. See Table 12, Distance of the Horizon.

Ashore, visibility is sometimes measured by a **transmissometer**, a device which measures the transparency of the atmosphere by passing a beam of light over a known short distance, and comparing it with a reference light.

3720. Upper Air Observations

Upper air information provides the third dimension to the weather map. Unfortunately, the equipment necessary to obtain such information is quite expensive, and the observations are time consuming. Consequently, the network of observing stations is quite sparse compared to that for surface observations, particularly over the oceans and in isolated land areas. Where facilities exist, upper air observations are made by means of unmanned balloons, in conjunction with theodolites, radiosondes, radar, and radio direction finders.

3721. New Technologies In Weather Observing

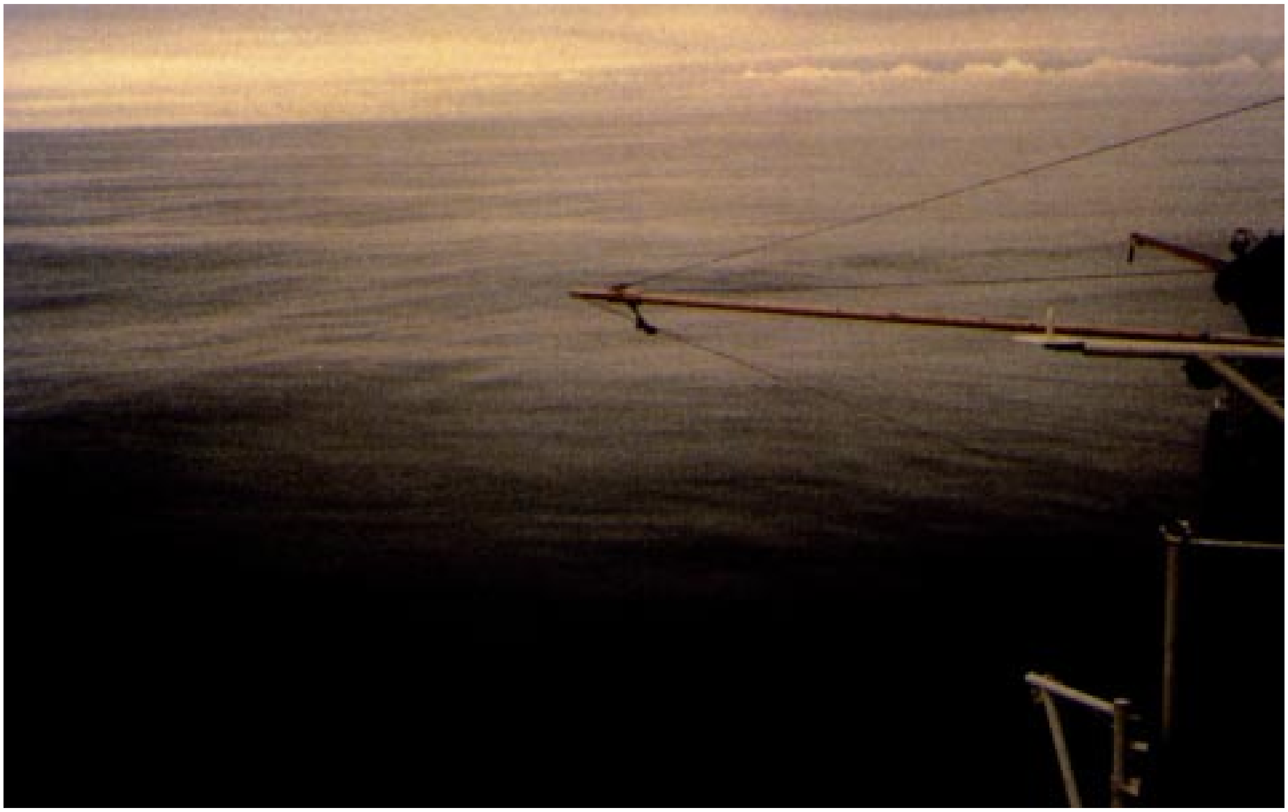
Radar and satellite observations are now almost universally used to forecast weather for both the short and long term. New techniques such as Doppler radar, and the integration of data from many different sites into complex computer algorithms provide a method of predicting storm tracks with a high degree of accuracy. Tornadoes, line squalls, individual thunderstorms, and entire storm systems can be continuously tracked and their paths predicted with unprecedented accuracy. At sea, the mariner has immediate access to this data through facsimile transmission of synoptic charts and actual satellite photographs, and through radio or communications satellite contact with weather routing services.

Automated weather stations and buoy systems provide regular transmissions of meteorological and oceanographic information by radio. They are generally used at isolated and relatively inaccessible locations from which weather and ocean data are of great importance. Depending on the type of system used, the elements usually measured include wind direction and speed, atmospheric pressure, air and sea surface temperature, spectral wave data, and a temperature profile from the sea surface to a predetermined depth.

Regardless of advances in the technology of observing and forecasting, the shipboard weather report remains the cornerstone upon which the accuracy of many forecasts is based. Each of the new observing methods is subject to limitations and occasional failures. The most reliable and complete source of weather data for offshore areas remains the shipboard observer.

3722. Recording Observations

Instructions for recording weather observations aboard vessels of the United States Navy are given in NAVMETOCCOMINST 3144.1 (series), Shipboard Weather Observations. Instructions for recording observations aboard merchant vessels are given in the National Weather Service Observing Handbook No. 1, Marine Surface Observations.



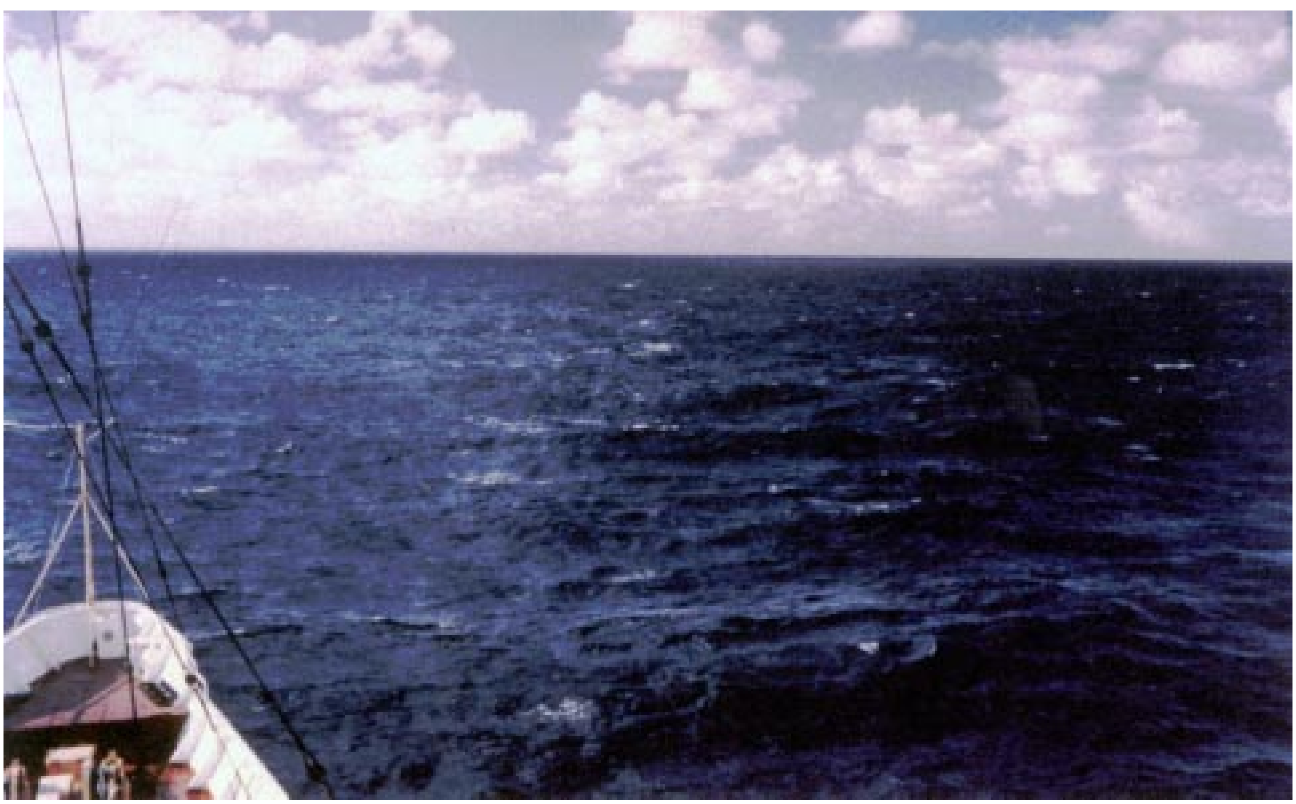
Force 0: Wind Speed less than 1 knot.
Sea: Sea like a mirror.

Force 1: Wind Speed 1-3 knots.
Sea: Wave height .1m (.25 ft); Ripples with appearance of scales, no foam crests.

Force 2: Wind Speed 4-6 knots.
Sea: Wave height .2-.3m (.5-1 ft); Small wavelets, crests of glassy appearance, not breaking.

Force 3: Wind Speed 7-10 knots.
Sea: Wave height .6-1m (2-3 ft); Large wavelets, crests begin to break, scattered whitecaps.

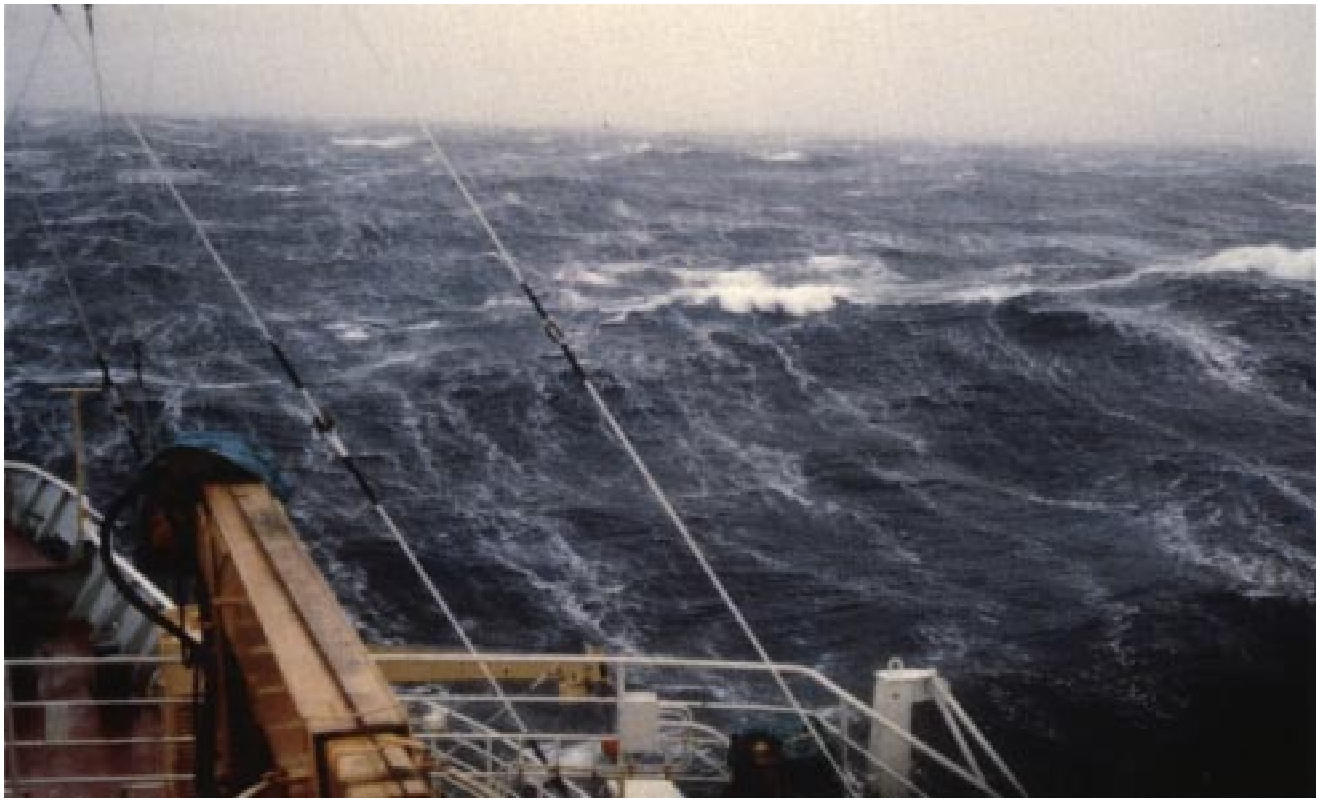
Force 4: Wind Speed 11-16 knots.
Sea: Wave height 1-1.5m (3.5-5 ft); Small waves becoming longer, numerous whitecaps.



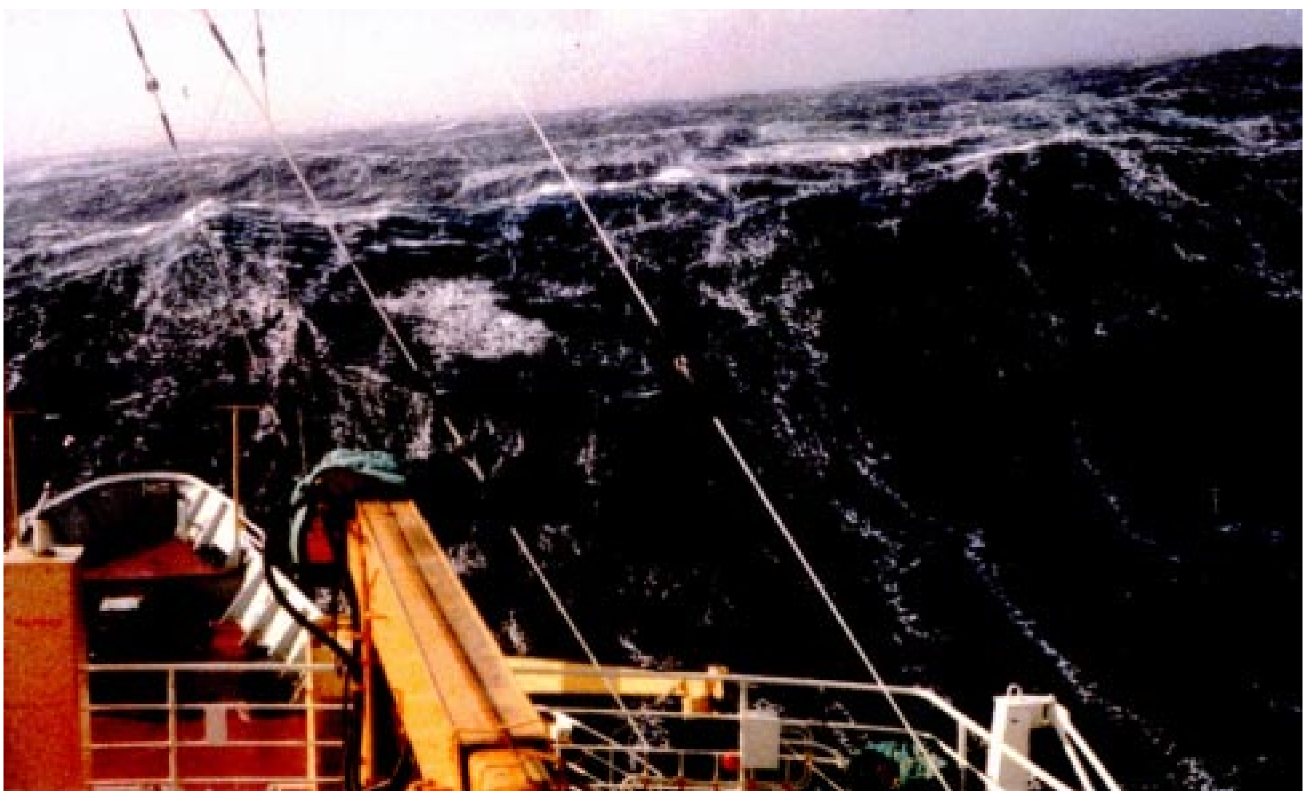
Force 5: Wind Speed 17-21 knots.
Sea: Wave height 2-2.5m (6-8 ft); Moderate waves, taking longer form, many whitecaps, some spray.

Force 6: Wind Speed 22-27 knots.
Sea: Wave height 3-4m (9.5-13 ft); Larger waves forming, whitecaps everywhere, more spray.

Force 7: Wind Speed 28-33 knots.
Sea: Wave height 4-5.5m (13.5-19 ft); sea heaps up, white foam from breaking waves begins to be blown in streaks along direction of wind.



Force 8: Wind Speed 34-40 knots.
Sea: Wave height 5.5-7.5m (18-25 ft); Moderately high waves of greater length, edges of crests begin to break into spindrift, foam is blown in well marked streaks.



Force 9: Wind Speed 41-47 knots.
Sea: Wave height 7-10m (23-32 ft); High waves, sea begins to roll, dense streaks of foam along wind direction, spray may reduce visibility.

Force 10: Wind Speed 48-55 knots (storm).
Sea: Wave height 9-12.5m (29-41 ft); Very high waves with overhanging crests, sea takes white appearance as foam is blown in very dense streaks, rolling is heavy and shocklike, visibility is reduced.

Force 11: Wind Speed 56-63 knots.
Sea: Wave height 11.5-16m (37-52 ft); Exceptionally high waves, sea covered with white foam patches, visibility still more reduced.

CHAPTER 38

WEATHER ROUTING

PRINCIPLES OF WEATHER ROUTING

3800. Introduction

Ship weather routing develops an optimum track for ocean voyages based on forecasts of weather, sea conditions, and a ship's individual characteristics for a particular transit. Within specified limits of weather and sea conditions, the term optimum is used to mean maximum safety and crew comfort, minimum fuel consumption, minimum time underway, or any desired combination of these factors. The purpose of this chapter is to acquaint the mariner with the basic philosophy and procedures of ship weather routing as an aid to understanding the routing agency's recommendations.

The mariner's first resources for route planning in relation to weather are the Pilot Chart Atlases and the Sailing Directions (Planning Guides). These publications give climatic data, such as wave height frequencies and ice limits, for the major ocean basins of the world. They recommend specific routes based on probabilities, but not on specific conditions.

The ship routing agency, acting as an advisory service, attempts to avoid or reduce the effects of specific adverse weather and sea conditions by issuing initial route recommendations prior to sailing, recommendations for track changes while underway (diversions), and weather advisories to alert the commanding officer or master about approaching unfavorable weather and sea conditions which cannot be effectively avoided by a diversion. Adverse weather and sea conditions are defined as those conditions which will cause damage, significant speed reduction, or time loss.

The initial route recommendation is based on a survey of weather and sea forecasts between the point of departure and the destination. It takes into account the hull type, speed capability, cargo, and loading conditions. The ship's progress is continually monitored, and, if adverse weather and sea conditions are forecast along the ship's current track, a recommendation for a diversion or weather advisory is transmitted to the ship. By this process of initial route selection and continued monitoring of the ship's progress for possible changes in the forecast weather and sea conditions along a route, it is possible to maximize the ship's speed and safety.

In providing optimum sailing conditions, the advisory service also attempts to reduce transit time by avoiding the adverse conditions which may be encountered on a shorter route, or if the forecasts permit, diverting to a shorter track to take advantage of favorable weather and sea conditions. The greatest potential advantage for this ship weather routing exists when: (1) the passage is relatively long, about 1,500 miles or more; (2) the waters are navigationally unrestricted, so that there is a choice of routes; and (3) weather is a factor in determining the route to be followed.

Use of this advisory service in no way relieves the commanding officer or master of responsibility for prudent seamanship and safe navigation. There is no intent by the routing agency to inhibit the exercise of professional judgment and prerogatives of commanding officers and masters.

3801. Historical Perspective

The advent of extended range forecasting and the development of selective climatology, along with powerful computer modeling techniques, have made ship routing systems possible. The ability to effectively advise ships to take advantage of favorable weather was hampered previously by forecast limitations and the lack of an effective communications system.

Development work in the area of data accumulation and climatology has a long history. Benjamin Franklin, as deputy postmaster general of the British Colonies in North America, produced a chart of the Gulf Stream from information supplied by masters of New England whaling ships. This first mapping of the Gulf Stream helped improve the mail packet service between the British Colonies and England. In some passages the sailing time was reduced by as much as 14 days over routes previously sailed. In the mid-19th century, Matthew Fontaine Maury compiled large amounts of atmospheric and oceanographic data from ships' log books. For the first time, a climatology of ocean weather and currents of the world was available to the mariner. This information was used by Maury to develop seasonally recommended routes for sailing ships and early steam powered vessels in the latter half of the 19th century. In many cases, Maury's charts were proved correct by the savings in transit time. Average transit time on the New York to California via Cape Horn route was reduced from 183 days to 139 days with the use of his recommended seasonal routes.

In the 1950's the concept of ship weather routing was put into operation by several private meteorological groups and by the U.S. Navy. By applying the available surface and upper air forecasts to transoceanic shipping, it was possible to effectively avoid much heavy weather while generally

sailing shorter routes than previously.

Optimum Track Ship Routing (OTSR), the ship routing service of the U.S. Navy, utilizes short range and extended range forecasting techniques in route selection and surveillance procedures. The short range dynamic forecasts of 3 to 5 days are derived from meteorological equations. These forecasts are computed twice daily from a data base of northern hemisphere surface and upper air observations, and include surface pressure, upper air constant pressure heights, and the spectral wave values. A significant increase in data input, particularly from satellite information over ocean areas, can extend the time period for which these forecasts are useful.

For extended range forecasting, generally 3 to 14 days, a computer searches a library of historical northern hemisphere surface pressure and 500 millibar analyses for an analogous weather pattern. This is an attempt at selective climatology by matching the current weather pattern with past weather patterns and providing a logical sequence-of-events forecast for the 10 to 14 day period following the dynamic forecast. It is performed for both the Atlantic and Pacific Oceans using climatological data for the entire period of data stored in the computer. For longer ocean transits, monthly values of wind, seas, fog, and ocean currents are used to further extend the time range.

Aviation was first in applying the principle of minimum time tracks (MTT) to a changing wind field. But the problem of finding an MTT for a specific flight is much simpler than for a transoceanic ship passage because an aircraft's transit time is much shorter than a ship's. Thus, marine minimum time tracks require significantly longer range forecasts to develop an optimum route.

Automation has enabled ship routing agencies to develop realistic minimum time tracks. Computation of minimum time tracks makes use of:

1. A navigation system to compute route distance, time enroute, estimated times of arrival (ETA's), and to provide 6 hourly DR synoptic positions for the range of the dynamic forecasts for the ship's current track.
2. A surveillance system to survey wind, seas, fog, and ocean currents obtained from the dynamic and climatological fields.
3. An environmental constraint system imposed as part of the route selection and surveillance process. Constraints are the upper limits of wind and seas desired for the transit. They are determined by the ship's loading, speed capability, and vulnerability. The constraint system is an important part of the route selection process and acts as a warning system when the weather and sea forecast along the present track exceeds predetermined limits.
4. Ship speed characteristics used to approximate ship's speed of advance (SOA) while transiting the forecast sea states.

Ship weather routing services are being offered by many nations. These include Japan, United Kingdom, Russia, Netherlands, Germany, and the United States. Also, several private firms provide routing services to shipping industry clients.

There are two general types of commercial ship routing services. The first uses techniques similar to the Navy's OTSR system to forecast conditions and compute routing recommendations. The second assembles and processes weather and sea condition data and transmits this to ships at sea for on-board processing and generation of route recommendations. The former system allows for greater computer power to be applied to the routing task because powerful computers are available ashore. The latter system allows greater flexibility to the ship's master in changing parameters, selecting routes, and displaying data.

3802. Ship And Cargo Considerations

Ship and cargo characteristics have a significant influence on the application of ship weather routing. Ship size, speed capability, and type of cargo are important considerations in the route selection process prior to sailing and the surveillance procedure while underway. A ship's characteristics identify its vulnerability to adverse conditions and its ability to avoid them.

Generally, ships with higher speed capability and less cargo encumbrances will have shorter routes and be better able to maintain near normal SOA's than ships with lower speed capability or cargoes. Some routes are unique because of the type of ship or cargo. Avoiding one element of weather to reduce pounding or rolling may be of prime importance. For example, a 20 knot ship with a heavy deck cargo may be severely hampered in its ability to maintain a 20 knot SOA in any seas exceeding moderate head or beam seas because of the possibility of damage resulting from the deck load's characteristics. A similar ship with a stable cargo under the deck is not as vulnerable and may be able to maintain the 20 knot SOA in conditions which would drastically slow the deck-loaded vessel. In towing operations, a tug is more vulnerable to adverse weather and sea conditions, not only in consideration of the tow, but also because of its already limited speed capability. Its slow speed adds to the difficulty of avoiding adverse weather and sea conditions.

Ship performance curves (speed curves) are used to estimate the ship's SOA while transiting the forecast sea states. The curves indicate the effect of head, beam, and following seas of various significant wave heights on the ship's speed. Figure 3802 is a performance curve prepared for an 18 knot vessel.

With the speed curves it is possible to determine just how costly a diversion will be in terms of the required distance and time. A diversion may not be necessary where the duration of the adverse conditions is limited. In this case, it may be better to ride out the weather and seas knowing that

a diversion, even if able to maintain the normal SOA, will not overcome the increased distance and time required.

At other times, the diversion track is less costly because it avoids an area of adverse weather and sea conditions, while being able to maintain normal SOA even though the distance to destination is increased. Based on input data for environmental conditions and ship's behavior, route selection and surveillance techniques seek to achieve the optimum balance between time, distance, and acceptable environmental and seakeeping conditions. Although speed performance curves are an aid to the ship routing agency, the response by mariners to deteriorating weather and sea conditions is not uniform. Some reduce speed voluntarily or change heading sooner than others when unfavorable conditions are encountered. Certain waves with characteristics such that the ship's bow and stern are in successive crests and troughs present special problems for the mariner. Being nearly equal to the ship's length, such wavelengths may induce very dangerous stresses. The degree of hogging and sagging and the associated danger may be more apparent to the mariner than to the ship routing agency. Therefore, adjustment in course and speed for a more favorable ride may be initiated by the commanding officer or master when this situation is encountered.

3803. Environmental Factors

Environmental factors of importance to ship weather routing are those elements of the atmosphere and ocean that may produce a change in the status of a ship transit. In ship routing, consideration is given to wind, seas, fog, ice, and ocean currents. While all of the environmental factors are important for route selection and surveillance, optimum routing is normally considered attained if the effects of wind and seas can be optimized.

Wind: The effect of wind speed on ship performance is difficult to determine. In light winds (less than 20-knots), ships lose speed in headwinds and gain speed slightly in following winds. For higher wind speeds, ship speed is reduced in both head and following winds. This is due to the increased wave action, which even in following seas results in increased drag from steering corrections, and indicates the importance of sea conditions in determining ship performance. In dealing with wind, it is also necessary to know the ship's sail area. High winds will have a greater adverse effect on a large, fully loaded container ship or car carrier than a fully loaded tanker of similar length. This effect is most noticeable when docking, but the effect of beam winds over several days at sea can also be considerable.

Wave Height: Wave height is the major factor affecting ship performance. Wave action is responsible for ship motions which reduce propeller thrust and cause increased drag from steering corrections. The relationship of ship speed to wave direction and height is similar to that of wind. Head seas reduce ship speed, while following seas increase ship speed slightly to a certain point, beyond which they retard it. In heavy seas, exact performance may be difficult to predict because of the adjustments to course and speed for shiphandling and comfort. Although the effect of sea and swell is much greater than wind, it is difficult to separate the two in ship routing.

In an effort to provide a more detailed description of the actual and forecast sea state, the U.S. Navy Fleet Numerical Meteorology and Oceanography Center,

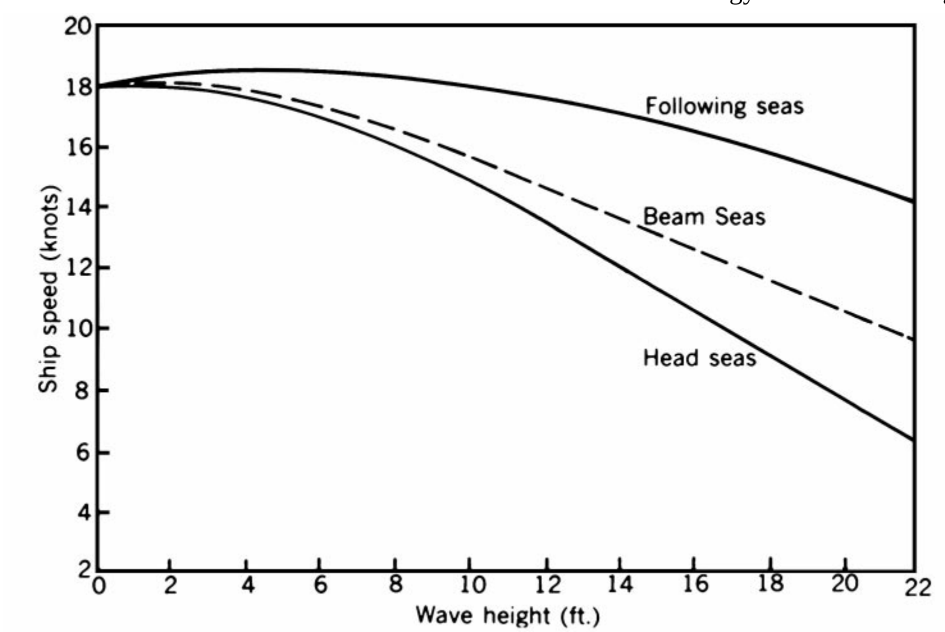


Figure 3802. Performance curves for head, beam, and following seas.

Monterey, California, produces the Global Spectral Ocean Wave Model (GSOWM) for use by the U.S. Navy's Optimum Track Ship Routing (OTSR) service. This model provides energy values from 12 different directions (30° sectors) and 15 frequency bands for wave periods from 6 to 26 seconds with the total wave energy propagated throughout the grid system as a function of direction and frequency. It is based on the analyzed and forecast planetary boundary layer model wind fields, and is produced for both the Northern and Southern Hemispheres out to 72 hours. For OTSR purposes, primary and secondary waves are derived from the spectral wave program, where the primary wave train has the principal energy (direction and frequency), and the secondary has to be 20 percent of the primary.

Fog: Fog, while not directly affecting ship performance, should be avoided as much as feasible, in order to maintain normal speed in safe conditions. Extensive areas of fog during summertime can be avoided by selecting a lower latitude route than one based solely upon wind and seas. Although the route may be longer, transit time may be less due to not having to reduce speed in reduced visibility. In addition, crew fatigue due to increased watchkeeping vigilance can be reduced.

North Wall Effect: During the Northern Hemisphere fall and winter, the waters to the north of the Gulf Stream in the North Atlantic are at their coldest, while the Gulf Stream itself remains at a constant relatively warm temperature. After passage of a strong cold front or behind a developing coastal low pressure system, Arctic air is sometimes drawn off the Mid-Atlantic coast of the United States and out over the warm waters of the Gulf Stream by northerly winds. This cold air is warmed as it passes over the Gulf Stream, resulting in rapid and intense deepening of the low pressure system and higher than normal surface winds. Higher waves and confused seas result from these winds. When these winds oppose the northeast set of the current, the result is increased wave heights and a shortening of the wave period. If the opposing current is sufficiently strong, the waves will break. These phenomena are collectively called the “North Wall Effect,” referring to the region of most dramatic temperature change between the cold water to the north and the warm Gulf Stream water to the south. The most dangerous aspect of this phenomenon is that the strong winds and extremely high, steep waves occur in a limited area and may develop without warning. Thus, a ship that is laboring in near-gale force northerly winds and rough seas, proceeding on a northerly course, can suddenly encounter storm force winds and dangerously high breaking seas. Numerous ships have foundered off the North American coast in the approximate position of the Gulf Stream's North Wall. A similar phenomenon occurs in the North Pacific near the Kuroshio Current and off the Southeast African coast near the Agulhas Current.

Ocean Currents: Ocean currents do not present a significant routing problem, but they can be a determining factor in route selection and diversion. This is especially true when the points of departure and destination are at relatively low latitudes. The important considerations to be evaluated are the difference in distance between a great-circle route and a route selected for optimum current, with the expected increase in SOA from the following current, and the decreased probability of a diversion for weather and seas at the lower latitude. For example, it has proven beneficial to remain equatorward of approximately 22°N for westbound passages between the Canal Zone and southwest Pacific ports. For eastbound passages, if the maximum latitude on a great-circle track from the southwest Pacific to the Canal Zone is below 24°N, a route passing near the axis of the Equatorial Countercurrent is practical because the increased distance is offset by favorable current. Direction and speed of ocean currents are more predictable than wind and seas, but some variability can be expected. Major ocean currents can be disrupted for several days by very intense weather systems such as hurricanes and by global phenomena such as El Nino.

Ice: The problem of ice is twofold: floating ice (icebergs) and deck ice. If possible, areas of icebergs or pack ice should be avoided because of the difficulty of detection and the potential for collision. Deck ice may be more difficult to contend with from a ship routing point of view because it is caused by freezing weather associated with a large weather system. While mostly a nuisance factor on large ships, it causes significant problems with the stability of small ships.

Latitude: Generally, the higher the latitude of a route, even in the summer, the greater are the problems with the environment. Certain operations should benefit from seasonal planning as well as optimum routing. For example, towing operations north of about 40° latitude should be avoided in non-summer months if possible.

3804. Synoptic Weather Considerations

A ship routing agency should direct its forecasting skills to avoiding or limiting the effect of weather and seas associated with extratropical low pressure systems in the mid and higher latitudes and the tropical systems in low latitude. Seasonal or monsoon weather is also a factor in route selection and diversion in certain areas.

Despite the amount of attention and publicity given to tropical cyclones, mid-latitude low pressure systems generally present more difficult problems to a ship routing agency. This is primarily due to the fact that major ship traffic is sailing in the latitudes of the migrating low pressure systems, and the amount of potential exposure to intense weather systems, especially in winter, is much greater.

Low pressure systems weaker than gale intensity (winds less than 34 knots) are not a severe problem for most ships. However, a relatively weak system may generate prolonged periods of rough seas which may hamper normal

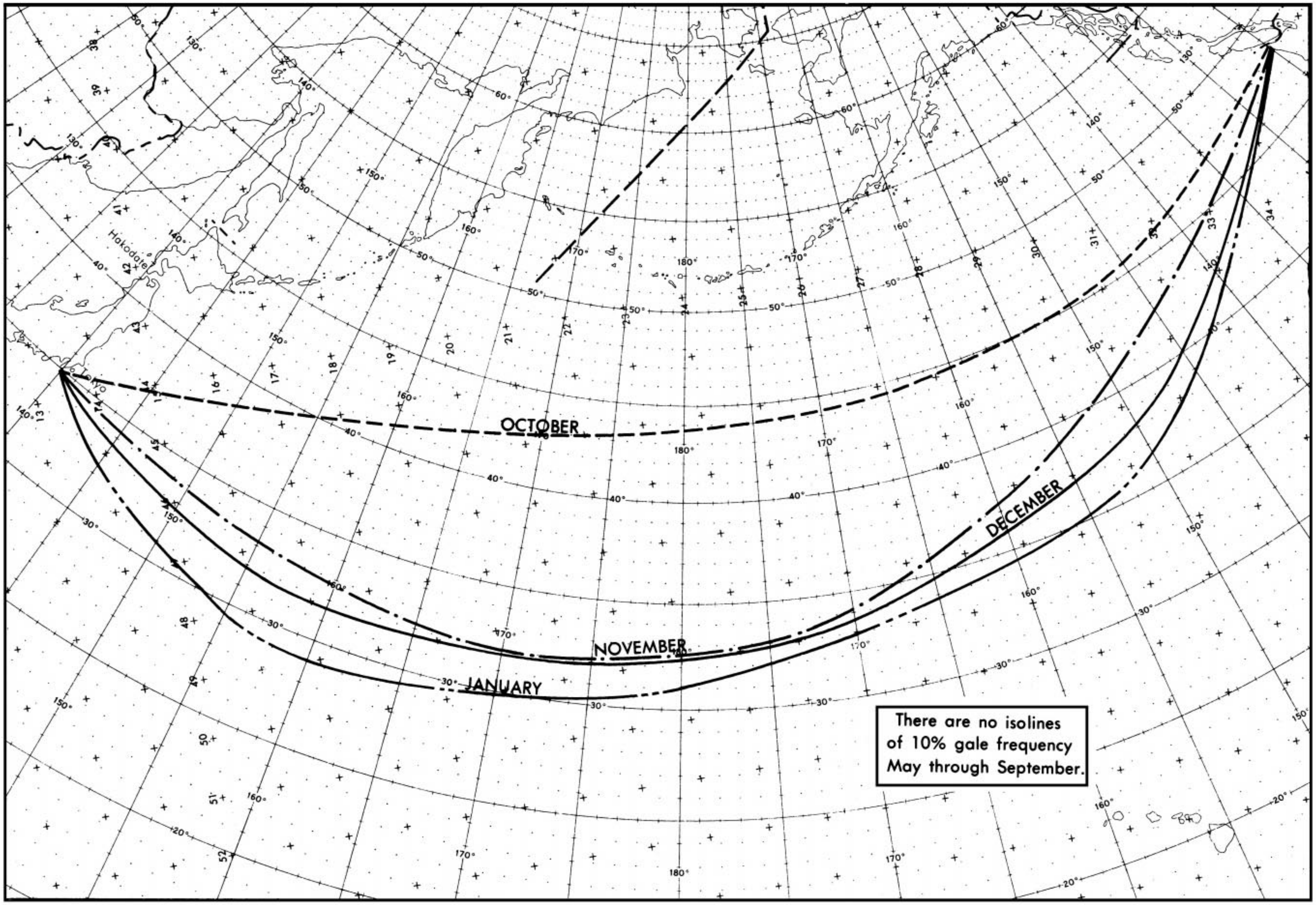


Figure 3804a. Generalized 10% frequency isolines of gale force winds for October through January.

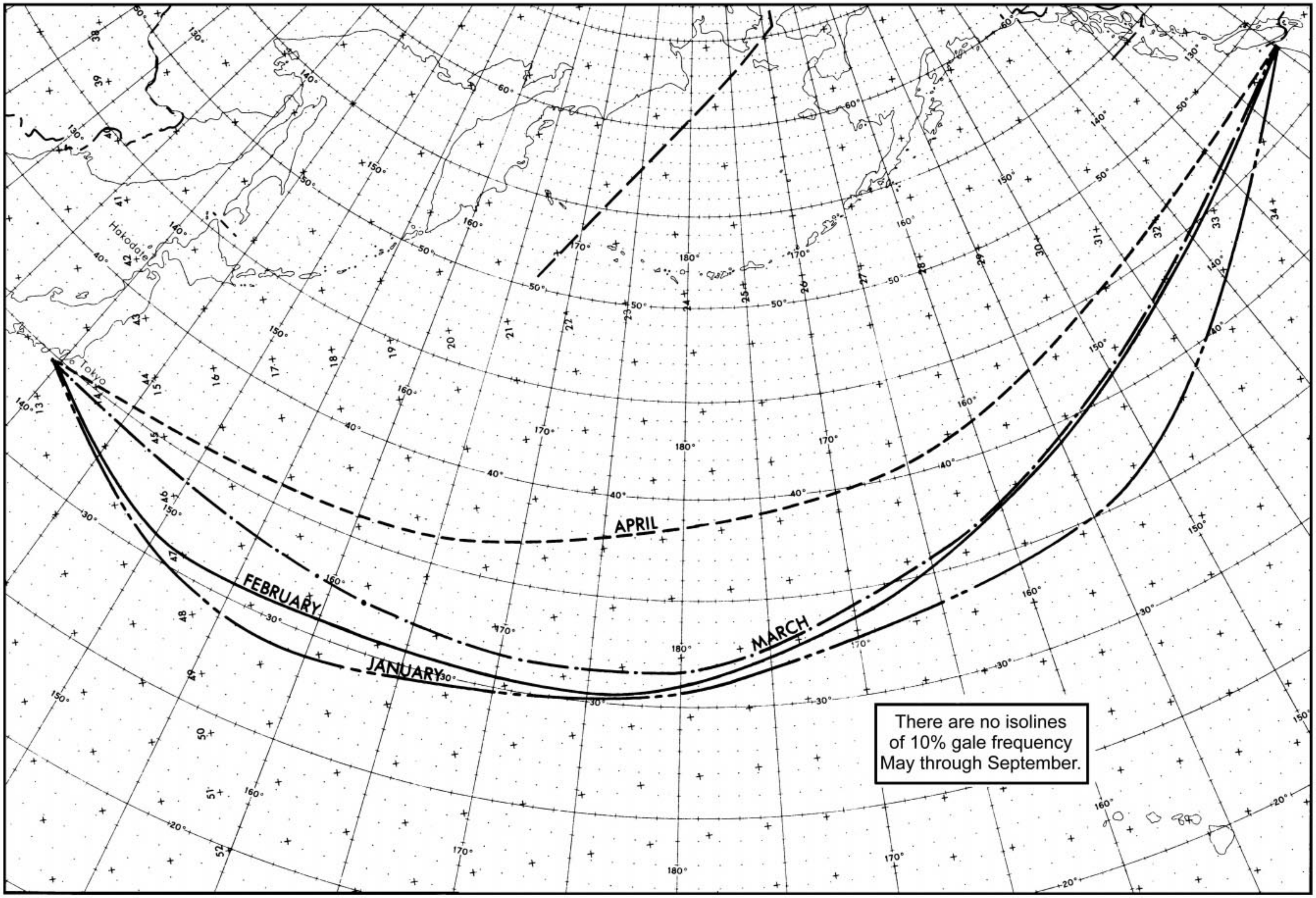


Figure 3804b. Generalized 10% frequency isolines of gale force winds for January through April..

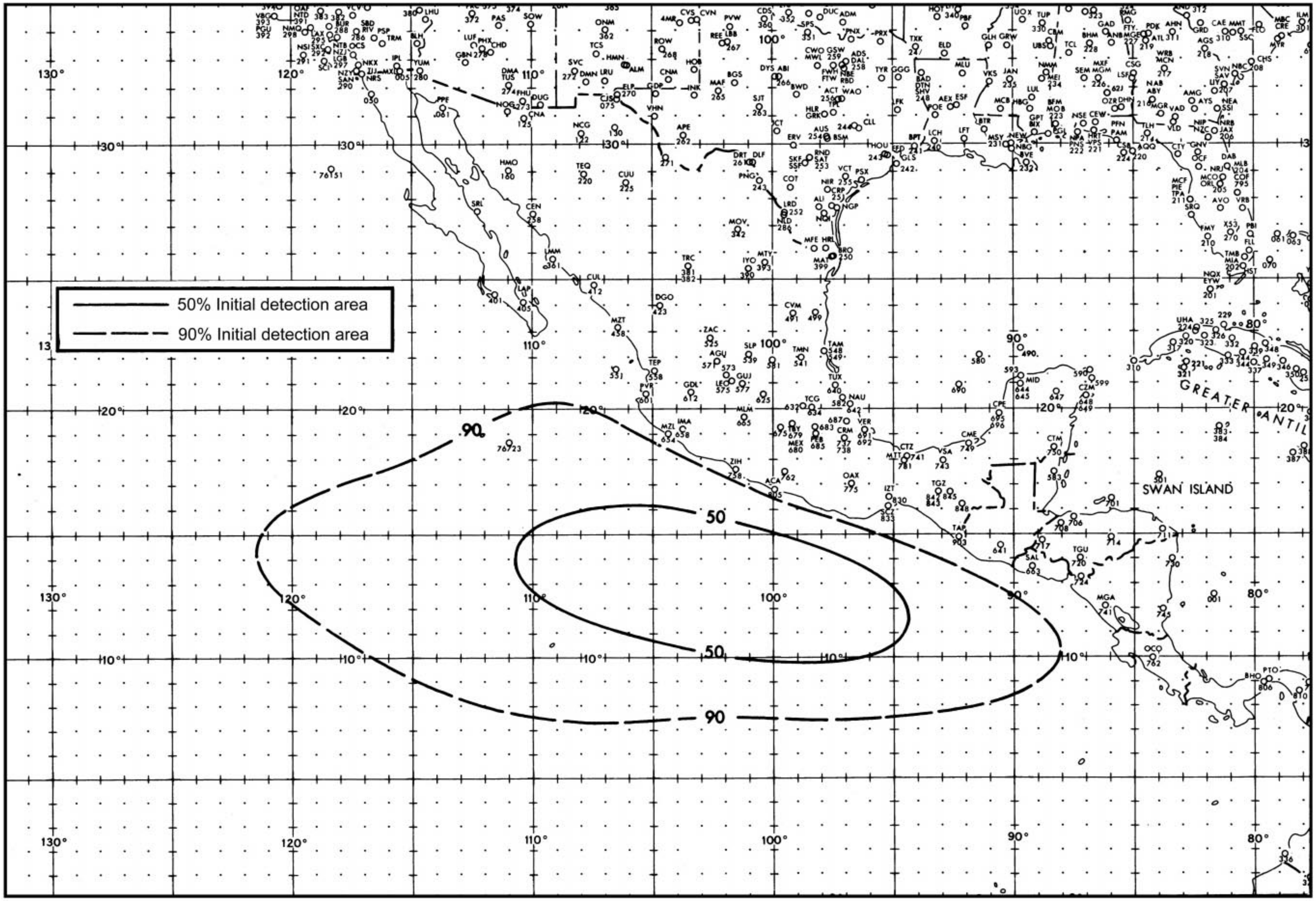


Figure 3804c. Area of initial detection of high percentage of tropical cyclones which later developed to tropical storm or typhoon intensity, 1957-1974.

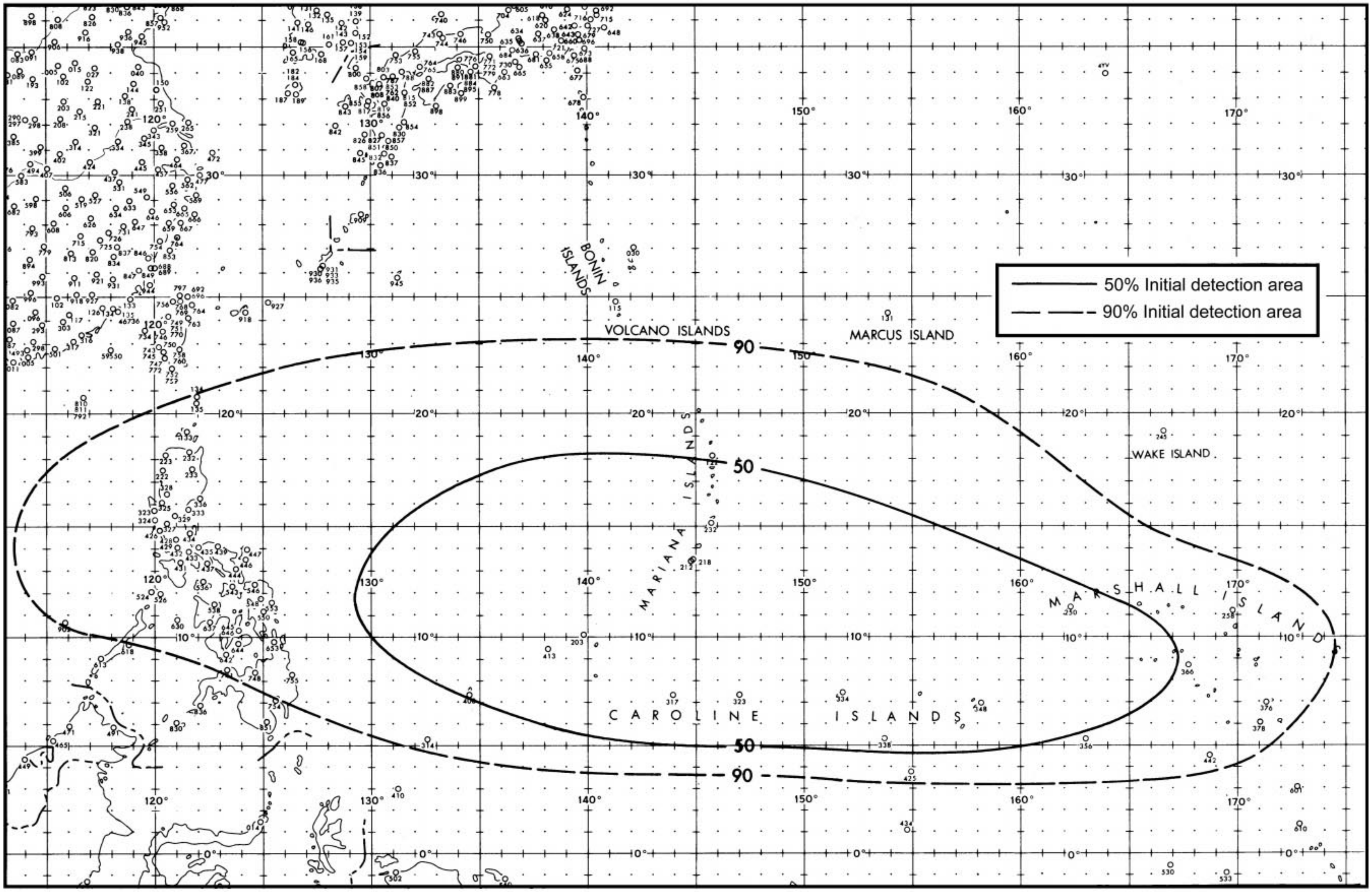


Figure 3804d.. Area of initial detection of high percentage of tropical cyclones which later developed to tropical storm or hurricaine intensity, 1946-1973

work aboard ship. Ship weather routing can frequently limit rough conditions to short periods of time and provide more favorable conditions for most of the transit. Relatively small ships, tugs with tows, low powered ships, and ships with sensitive cargoes can be significantly affected by weather systems weaker than gale intensity. Using a routing agency can be beneficial.

Gales (winds 34 to 47 knots) and storms (winds greater than 48 knots) in the open sea can generate very rough or high seas, particularly when an adverse current such as the Gulf Stream is involved. This can force a reduction in speed in order to gain a more comfortable and safe ride. Because of the extensive geographic area covered by a well developed low pressure system, once ship's speed is reduced the ability to improve the ship's situation is severely hampered. Thus, exposure to potential damage and danger is greatly increased. A recommendation for a diversion by a routing agency well in advance of the intense weather and associated seas will limit the duration of exposure of the ship. If effective, ship speed will not be reduced and satisfactory progress will be maintained even though the remaining distance to destination is increased. Overall transit time is usually shorter than if no track change had been made and the ship had remained in heavy weather. In some cases diversions are made to avoid adverse weather conditions and shorten the track at the same time. Significant savings in time and costs can result.

In very intense low pressure systems, with high winds and long duration over a long fetch, seas will be generated and propagated as swell over considerable distances. Even on a diversion, it is difficult to effectively avoid all unfavorable conditions. Generally, original routes for transoceanic passages, issued by the U.S. Navy's ship routing service, are equatorward of the 10% frequency isoline for gale force winds for the month of transit, as interpreted from the U.S. Navy's Marine Climatic Atlas of the World. These are shown in Figure 3804a and Figure 3804b for the Pacific. To avoid the area of significant gale activity in the Atlantic from October to April, the latitude of transit is generally in the lower thirties.

The areas, seasons, and the probability of development of tropical cyclones are fairly well defined in climatological publications. In long range planning, considerable benefit can be gained by limiting the exposure to the potential hazards of tropical systems.

In the North Pacific, avoid areas with the greatest probability of tropical cyclone formation. Avoiding existing tropical cyclones with a history of 24 hours or more of 6-hourly warnings is in most cases relatively straightforward. However, when transiting the tropical cyclone generating area, the ship under routing may provide the first report of environmental conditions indicating that a new disturbance is developing. In the eastern North Pacific the generating area for a high percentage of tropical cyclones is relatively compact (Figure 3804c). Remain south of a line from lat. 9°N, long. 90°W to lat. 14°N, long. 115°W. In the western North Pacific it is advisable to hold north of 22°N when no tropical systems are known to exist. See Figure 3804d.

In the Atlantic , sail near the axis of the Bermuda high or northward to avoid the area of formation of tropical cyclones. Of course, avoiding an existing tropical cyclone takes precedence over avoiding a general area of potential development.

It has proven equally beneficial to employ similar considerations for routing in the monsoon areas of the Indian Ocean and the South China Sea. This is accomplished by providing routes and diversions that generally avoid the areas of high frequency of gale force winds and associated heavy seas, as much as feasible. Ships can then remain in satisfactory conditions with limited increases in route distance.

Depending upon the points of departure and destination, there are many combinations of routes that can be used when transiting the northern Indian Ocean (Arabian Sea, Bay of Bengal) and the South China Sea. For example, in the Arabian Sea during the summer monsoon, routes to and from the Red Sea, the western Pacific, and the eastern Indian Ocean should hold equatorward. Ships proceeding to the Persian Gulf during this period are held farther south and west to put the heaviest seas on the quarter or stern when transiting the Arabian Sea. Eastbound ships departing the Persian Gulf may proceed generally east southeast toward the Indian subcontinent, then south, to pass north and east of the highest southwesterly seas in the Arabian Sea. Westbound ships out of the Persian Gulf for the Cape of Good Hope appear to have little choice in routes unless considerable distance is added to the transit by passing east of the highest seas. In the winter monsoon, routes to or from the Red Sea for the western Pacific and the Indian Ocean are held farther north in the Arabian Sea to avoid the highest seas. Ships proceeding to the Persian Gulf from the western Pacific and eastern Indian Ocean may hold more eastward when proceeding north in the Arabian Sea. Ships departing the Persian Gulf area will have considerably less difficulty than during the summer monsoon. Similar considerations can be given when routing ships proceeding to and from the Bay of Bengal.

In the South China Sea, transits via the Palawan Passage are recommended when strong, opposing wind and seas are forecast. This is especially true during the winter monsoon. During periods when the major monsoon flow is slack, ships can use the shortest track as conditions permit.

3805. Special Weather And Environmental Considerations

In addition to the synoptic weather considerations in ship weather routing, there are special environmental problems that can be avoided by following recommendations and advisories of ship routing agencies. These problems generally cover a smaller geographic area and are seasonal in nature, but are still important to ship routing.

In the North Atlantic, because of heavy shipping traffic, frequent poor visibility in rain or fog, and restricted navigation, particularly east of Dover Strait, some mariners

prefer to transit to or from the North Sea via Pentland Firth, passing north of the British Isles rather than via the English Channel.

Weather routed ships generally avoid the area of dense fog with low visibility in the vicinity of the Grand Banks off Newfoundland and the area east of Japan north of 35°N. Fishing vessels in these two areas provide an added hazard to safe navigation. This condition exists primarily from June through September. Arctic supply ships en route from the U.S. east coast to the Davis Strait-Baffin Bay area in the summer frequently transit via Cabot Strait and the Strait of Belle Isle, where navigation aids are available and icebergs are generally grounded.

Icebergs are a definite hazard in the North Atlantic from late February through June, and occasionally later. The hazard of floating ice is frequently combined with restricted visibility in fog. International Ice Patrol reports and warnings are incorporated into the planning of routes to safely avoid dangerous iceberg areas. It is usually necessary to hold south of at least 45°N until well southeast of Newfoundland. The U.S. Navy ship routing office at the Naval Atlantic Meteorology and Oceanography Center in Norfolk maintains a safety margin of at least 100 miles from icebergs reported by the International Ice Patrol. Also, in a severe winter, the Denmark Strait may be closed by ice.

In the northern hemisphere winter, a strong high pressure system moving southeast out of the Rocky Mountains brings cold air down across Central America and the western Gulf of Mexico producing gale force winds in the Gulf of Tehuantepec. This fall wind is similar to the pampero, mistral, and bora of other areas of the world. An adjustment to ship's track can successfully avoid the highest seas associated with the "Tehuantepecer." For transits between the Canal Zone and northwest Pacific ports, little additional distance is required to avoid this area (in winter) by remaining south of at least 12°N when crossing 97°W. While avoiding the highest seas, some unfavorable swell conditions may be encountered south of this line. Ships transiting between the Panama Canal and North American west coast ports can stay close along the coast of the Gulf of Tehuantepec to avoid heavy seas during gale conditions, but may still encounter high offshore winds.

In the summer, the semi-permanent high pressure systems over the world's oceans produce strong equatorward flow along the west coasts of continents. This feature is most pronounced off the coast of California and Portugal in the Northern Hemisphere and along Chile, western Australia, and southwest Africa in the Southern Hemisphere. Very rough seas are generated and are considered a definite factor in route selection or diversion when transiting these areas.

3806. Types Of Recommendations And Advisories

An **initial route recommendation** is issued to a ship or routing authority normally 48 to 72 hours prior to sailing, and the process of surveillance begins. Surveillance is a continuous process, maintained until the ship arrives at its destination. Initial route recommendations are a composite representation of experience, climatology, weather and sea state forecasts, operational concerns, and the ship's seagoing characteristics. A planning route provides a best estimate of a realistic route for a specific transit period. Such routes are provided when estimated dates of departure (EDD's) are given to the routing agency well in advance of departure, usually a week to several months. Long range planning routes are based more on seasonal and climatological expectations than the current weather situation. While planning routes are an attempt to make extended range (more than a week) or long range (more than a month) forecasts, these recommendations are likely to be revised near the time of departure to reflect the current weather pattern. An initial route recommendation is more closely related to the current weather patterns by using the latest dynamic forecasts than are the planning route recommendations. These, too, are subject to revision prior to sailing, if weather and sea conditions warrant.

Adjustment of departure time is a recommendation for delay in departure, or early departure if feasible, and is intended to avoid or significantly reduce the adverse weather and seas forecast on the first portion of the route, if sailing on the original EDD. The initial route is not revised, only the timing of the ship's transit through an area with currently unfavorable weather conditions. Adjusting the departure time is an effective method of avoiding a potentially hazardous situation where there is no optimum route for sailing at the originally scheduled time.

A **diversion** is an underway adjustment in track and is intended to avoid or limit the effect of adverse weather conditions forecast to be encountered along the ship's current track. Ship's speed is expected to be reduced by the encounter with the heavy weather. In most cases the distance to destination is increased in attempting to avoid the adverse weather, but this is partially overcome by being able to maintain near normal SOA. Diversions are also recommended where satisfactory weather and sea conditions are forecast on a shorter track.

Adjustment of SOA is a recommendation for slowing or increasing the ship's speed as much as practicable, in an attempt to avoid an adverse weather situation by adjusting the timing of the encounter. This is also an effective means of maintaining maximum ship operating efficiency, while not diverting from the present ship's track. By adjusting the SOA, a major weather system can sometimes be avoided with no increase in distance. The development of fast ships (SOA greater than 30 knots) gives the ship routing agency the potential to "make the ship's weather" by adjusting the ship's speed and track for encounter with favorable weather conditions.

Evasion is a recommendation to the commanding officer or master to take independent action to avoid, as much as possible, a potentially dangerous weather system. The ship routing meteorologist may recommend a general direction for safe evasion but does not specify an exact track. The recommendation for evasion is an indication that the weather

and sea conditions have deteriorated to a point where shiphandling and safety are the primary considerations and progress toward destination has been temporarily suspended, or is at least of secondary consideration.

A **weather advisory** is a transmission sent to the ship advising the commanding officer or master of expected adverse conditions, their duration, and geographic extent. It is initiated by the ship routing agency as a service and an aid to the ship. The best example of a situation for which a forecast is helpful is when the ship is currently in good weather but adverse weather is expected within 24 hours for which a diversion has not been recommended, or a diversion where adverse weather conditions are still expected. This type of advisory may include a synoptic weather discussion, and a wind, seas, or fog forecast.

The ability of the routing agency to achieve optimum conditions for the ship is aided by the commanding officer or master adjusting course and speed where necessary for an efficient and safe ride. At times, the local sea conditions may dictate that the commanding officer or master take independent action.

3807. Southern Hemisphere Routing

Available data on which to base analyses and forecasts is generally very limited in the Southern Hemisphere. Weather and other environmental information obtained from satellites offers the possibility of improvement in southern hemisphere forecast products.

Passages south of the Cape of Good Hope and Cape Horn should be timed to avoid heavy weather as much as possible, since intense and frequent low pressure systems are common in these areas. In particular, near the southeast coasts of Africa and South America, intense low pressure systems form in the lee of relatively high terrain near the coasts of both continents. Winter transits south of Cape Horn are difficult, since the time required for transit is longer than the typical interval between storms. Remaining equatorward of about 35°S as much as practicable will limit exposure to adverse conditions. If the frequency of lows passing these areas is once every three or four days, the probability of encountering heavy weather is high.

Tropical cyclones in the Southern Hemisphere present a significant problem because of the sparse surface and upper air observations from which forecasts can be made. Satellites provide the most reliable means by which to obtain accurate positions of tropical systems, and also give the first indication of tropical cyclone formation.

In the Southern Hemisphere, OTSR and other ship weather routing services are available, but are limited in application because of sparse data reports, from which reliable short and extended range forecasts can be produced. Strong climatological consideration is usually given to any proposed southern hemisphere transit. OTSR procedures for the Northern Hemisphere can be instituted in the Southern Hemisphere whenever justified by basic data input and available forecast models.

3808. Communications

A vital part of a ship routing service is communication between the ship and the routing agency. Reports from the ship show the progress and ability to proceed in existing conditions. Weather reports from the ship enrich the basic data on which analyses are based and forecasts derived, assisting both the reporting ship and others in the vicinity.

Despite all efforts to achieve the best forecasts possible, the quality of forecasts does not always warrant maintaining the route selected. In the U.S. Navy's ship routing program, experience shows that one-third of the ships using OTSR receive some operational or weather-dependent change while underway.

The routing agency needs reports of the ship's position and the ability to transmit recommendations for track change or weather advisories to the ship. The ship needs both send and receive capability for the required information. Information on seakeeping changes initiated by the ship is desirable in a coordinated effort to provide optimum transit conditions. New satellite communications services are making possible the transmission of larger amounts of data than possible through traditional radio messages, a development which supports systems using on-board analysis to generate routes.

3809. Benefits

The benefits of ship weather routing services are primarily in cost reduction and safety. The savings in operating costs are derived from reductions in transit time, heavy weather encounters, fuel consumption, cargo and hull damage, and more efficient scheduling of dockside activities. The savings are further increased by fewer emergency repairs, more efficient use of personnel, improved topside working conditions, lower insurance rates as preferred risks under weather routing, and ultimately, extended ship operating life.

An effective routing service maximizes safety by greatly reducing the probability of severe or catastrophic damage to the ship, and injury of crew members. The efficiency and health of the crew is also enhanced by avoiding heavy weather. This is especially important on modern, automated ships with reduced crews.

3810. Conclusion

The success of ship weather routing is dependent upon the validity of the forecasts and the routing agency's ability to make appropriate route recommendations and diversions. Anticipated improvements in a routing agency's recommendations will come from advancements in meteorology, technology, and the application of ocean wave forecast models.

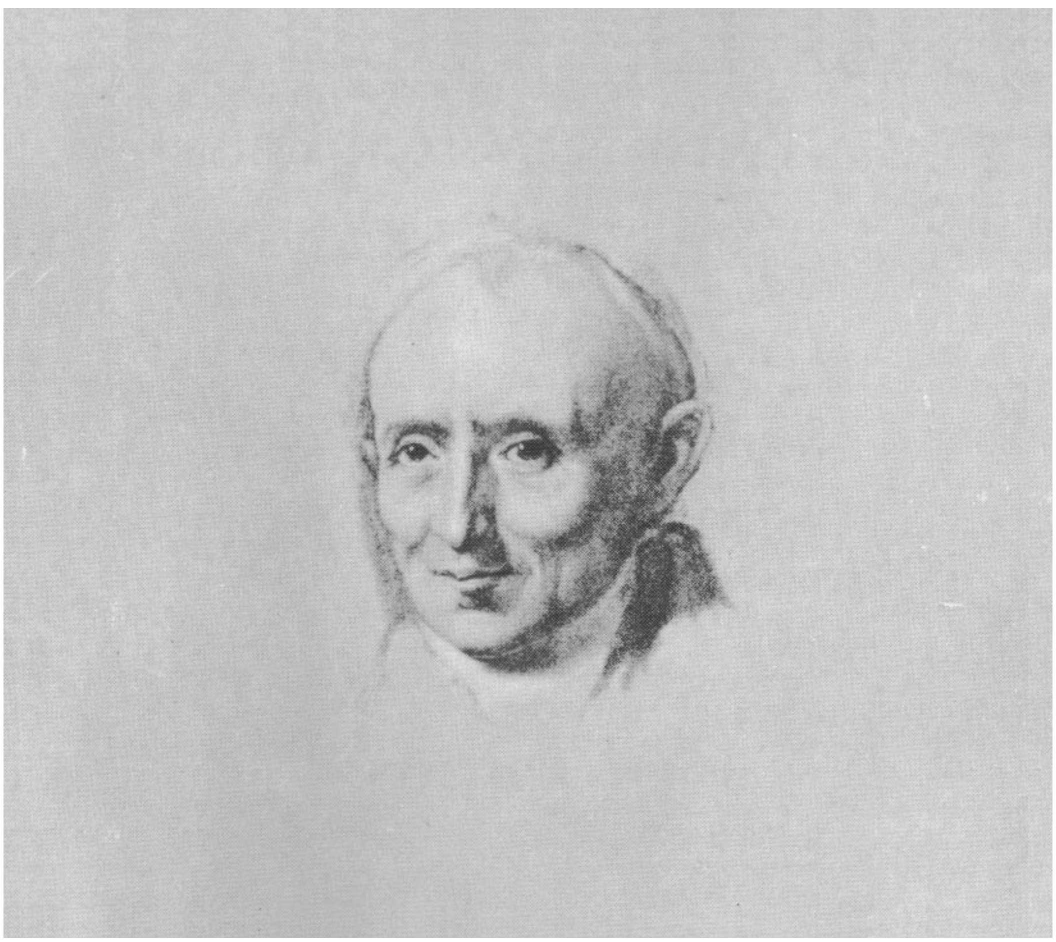
Advancements in mathematical meteorology, coupled with the continued application of computers, will extend the time range and accuracy of the dynamic and statistical forecasts.

Technological advancements in the areas of satellite and automated communications and onboard ship response systems will increase the amount and type of information to and from the ship with fewer delays. Ship response and performance data included with the ship's weather report will provide the routing agency with real-time information with which to ascertain the actual state of the ship. Being able to predict a ship's response in most weather and sea conditions will result in improved routing procedures.

Shipboard and anchored wave measuring devices contribute to the development of ocean wave analysis and forecast models. Shipboard seakeeping instrumentation, with input of measured wave conditions and predetermined ship response data for the particular hull, enables a master or commanding officer to adjust course and speed for actual conditions.

Modern ship designs, exotic cargoes, and sophisticated transport methods require individual attention to each ship's areas of vulnerability. Any improvement in the description of sea conditions by ocean wave models will improve the output from ship routing and seakeeping systems.

Advanced planning of a proposed transit, combined with the study of expected weather conditions, both before and during the voyage, as is done by ship routing agencies, and careful on board attention to seakeeping (with instrumentation if available) provide the greatest opportunity to achieve the goal of optimum environmental conditions for ocean transit.



Last painting by Gilbert Stuart (1828). Considered by the family of Bowditch to be the best of various paintings made, although it was unfinished when the artist died.

NATHANIEL BOWDITCH
(1773-1838)

Nathaniel Bowditch was born on March 26, 1773, in Salem, Mass., fourth of the seven children of shipmaster Habakkuk Bowditch and his wife, Mary.

Since the migration of William Bowditch from England to the Colonies in the 17th century, the family had resided at Salem. Most of its sons, like those of other families in this New England seaport, had gone to sea, and many of them became shipmasters. Nathaniel Bowditch himself sailed as master on his last voyage, and two of his brothers met untimely deaths while pursuing careers at sea.

It is reported that Nathaniel Bowditch's father lost two ships at sea, and by late Revolutionary days he returned to the trade of cooper, which he had learned in his youth. This provided insufficient income to properly supply the needs of his growing family, and hunger and cold were often experienced. For many years the nearly destitute family received an annual grant of 15 to 20 dollars from the Salem Marine Society. By the time Nathaniel had reached the age of 10, the family's poverty necessitated his leaving school and joining his father in the cooper's trade.

Nathaniel was unsuccessful as a cooper, and when he was about 12 years of age, he entered the first of two ship-chandlery firms by which he was employed. It was during the nearly 10 years he was so employed that his great mind first attracted public attention. From the time he began school Bowditch had an all-consuming interest in learning, particularly mathematics. By his middle teens he was recognized in Salem as an authority on that subject. Salem being primarily a shipping town, most of the inhabitants sooner or later found their way to the ship chandler, and news of the brilliant young clerk spread until eventually it came to the attention of the learned men of his day. Impressed by his desire to educate himself, they supplied him with books that he might learn of the discoveries of other men. Since many of the best books were written by Europeans, Bowditch first taught himself their languages. French, Spanish, Latin, Greek, and German were among the two dozen or more languages and dialects he studied during his life. At the age of 16 he began the study of Newton's *Principia*, translating parts of it from the Latin. He even found an error in that classic, and though lacking the confidence to announce it at the time, he later published his findings and had them accepted.

During the Revolutionary War a privateer out of Beverly, a neighboring town to Salem, had taken as one of its prizes an English vessel which was carrying the philosophical library of a famed Irish scholar, Dr. Richard Kirwan. The books were brought to the Colonies and there bought by a group of educated Salem men who used them to found the Philosophical Library Company, reputed to have been the best library north of Philadelphia at the time. In 1791, when Bowditch was 18, two Harvard-educated ministers, Rev. John Prince and Rev. William Bentley, persuaded the Company to allow Bowditch the use of its library. Encouraged by these two men and a third-Nathan Read, an apothecary and also a Harvard man-Bowditch studied the works of the great men who had preceded him, especially the mathematicians and the astronomers. By the time he became of age, this knowledge, acquired before and after his long working hours and in his spare time, had made young Bowditch the outstanding mathematician in the Commonwealth, and perhaps in the country.

In the seafaring town of Salem, Bowditch was drawn to navigation early, learning the subject at the age of 13 from an old British sailor. A year later he began studying surveying, and in 1794 he assisted in a survey of the town. At 15 he devised an almanac reputed to have been of great accuracy. His other youthful accomplishments included the construction of a crude barometer and a sundial.

When Bowditch went to sea at the age of 21, it was as captain's writer and nominal second mate, the officer's berth being offered him because of his reputation as a scholar. Under Captain Henry Prince, the ship *Henry* sailed from Salem in the winter of 1795 on what was to be a year-long voyage to the Ile de Bourbon (now called Reunion) in the Indian Ocean.

Bowditch began his seagoing career when accurate time was not available to the average naval or merchant ship. A reliable marine chronometer had been invented some 60 years before, but the prohibitive cost, plus the long voyages without opportunity to check the error of the timepiece, made the large investment an impractical one. A system of determining longitude by "lunar distance," a method which did not require an accurate timepiece, was known, but this product of the minds of mathematicians and astronomers was so involved as to be beyond the capabilities of the uneducated seamen of that day. Consequently, ships navigated by a combination of dead reckoning and parallel sailing (a system of sailing north or south to the latitude of the destination and then east or west to the destination). The navigational routine of the time was "lead, log, and lookout."

To Bowditch, the mathematical genius, computation of lunar distances was no mystery, of course, but he recognized the need for an easier method of working them in order to navigate ships more safely and efficiently. Through analysis and observation, he derived a new and simplified formula during his first trip.

John Hamilton Moore's *The Practical Navigator* was the leading navigational text when Bowditch first went to sea, and had been for many years. Early in his first voyage, however, the captain's writer-second mate began turning

up errors in Moore's book, and before long he found it necessary to recompute some of the tables he most often used in working his sights. Bowditch recorded the errors he found, and by the end of his second voyage, made in the higher capacity of supercargo, the news of his findings in *The New Practical Navigator* had reached Edmund Blunt, a printer at Newburyport, Mass. At Blunt's request, Bowditch agreed to participate with other learned men in the preparation of an American edition of the thirteenth (1798) edition of Moore's work. The first American edition was published at Newburyport by Blunt in 1799. This edition corrected many of the errors that Moore had failed to correct. Although most of the errors were of little significance to practical navigation as they were errors in the fifth and sixth places of logarithm tables, some errors were significant.

The most significant error was listing the year 1800 as a leap year in the table of the sun's declination. The consequence was that Moore gave the declination for MARCH 1, 1800, as 7°11'. Since the actual value was 7° 33', the calculation of a meridian altitude would be in error by 22 minutes of latitude.

Bowditch's principal contribution to the first American edition was his chapter "The Method of finding the Longitude at Sea," which was his new method for computing the lunar distance. Following publication of the first American edition, Blunt obtained Bowditch's services in checking the American and English editions for further errors. Blunt then published a second American edition of Moore's thirteenth edition in 1800. When preparing a third American edition for the press, Blunt decided that Bowditch had revised Moore's work to such an extent that Bowditch should be named as author. The title was changed to *The New American Practical Navigator* and the book was published in 1802 as a first edition. Bowditch vowed while writing this edition to "put down in the book nothing I can't teach the crew," and it is said that every member of his crew including the cook could take a lunar observation and plot the ship's position.

Bowditch made a total of five trips to sea, over a period of about nine years, his last as master and part owner of the three-masted *Putnam*. Homeward bound from a 13-month voyage to Sumatra and the Ile de France (now called Mauritius) the *Putnam* approached Salem harbor on December 25, 1803, during a thick fog without having had a celestial observation since noon on the 24th. Relying upon his dead reckoning, Bowditch conned his wooden-hulled ship to the entrance of the rocky harbor, where he had the good fortune to get a momentary glimpse of Eastern Point, Cape Ann, enough to confirm his position. The *Putnam* proceeded in, past such hazards as "Bowditch's Ledge" (named after a great-grandfather who had wrecked his ship on the rock more than a century before) and anchored safely at 1900 that evening. Word of the daring feat, performed when other masters were hove-to outside the harbor, spread along the coast and added greatly to Bowditch's reputation. He was, indeed, the "practical navigator."

His standing as a mathematician and successful shipmaster earned him a lucrative (for those times) position ashore within a matter of weeks after his last voyage. He was installed as president of a Salem fire and marine insurance company at the age of 30, and during the 20 years he held that position the company prospered. In 1823 he left Salem to take a similar position with a Boston insurance firm, serving that company with equal success until his death.

From the time he finished the "*Navigator*" until 1814, Bowditch's mathematical and scientific pursuits consisted of studies and papers on the orbits of comets, applications of Napier's rules, magnetic variation, eclipses, calculations on tides, and the charting of Salem harbor. In that year, however, he turned to what he considered the greatest work of his life, the translation into English of *Mecanique Celeste*, by Pierre Laplace. *Mecanique Celeste* was a summary of all the then known facts about the workings of the heavens. Bowditch translated four of the five volumes before his death, and published them at his own expense. He gave many formula derivations which Laplace had not shown, and also included further discoveries following the time of publication. His work made this information available to American astronomers and enabled them to pursue their studies on the basis of that which was already known. Continuing his style of writing for the learner, Bowditch presented his English version of *Mecanique Celeste* in such a manner that the student of mathematics could easily trace the steps involved in reaching the most complicated conclusions.

Shortly after the publication of *The New American Practical Navigator*, Harvard College honored its author with the presentation of the honorary degree of Master of Arts, and in 1816 the college made him an honorary Doctor of Laws. From the time the Harvard graduates of Salem first assisted him in his studies, Bowditch had a great interest in that college, and in 1810 he was elected one of its Overseers, a position he held until 1826, when he was elected to the Corporation. During 1826-27 he was the leader of a small group of men who saved the school from financial disaster by forcing necessary economies on the college's reluctant president. At one time Bowditch was offered a Professorship in Mathematics at Harvard but this, as well as similar offers from West Point and the University of Virginia, he declined. In all his life he was never known to have made a public speech or to have addressed any large group of people.

Many other honors came to Bowditch in recognition of his astronomical, mathematical, and marine accomplishments. He became a member of the American Academy of Arts and Sciences, the East India Marine Society, the Royal Academy of Edinburgh, the Royal Society of London, the Royal Irish Academy, the American Philosophical Society, the Connecticut Academy of Arts and Sciences, the Boston Marine Society, the Royal Astronomical Society, the Palermo Academy of Science, and the Royal Academy of Berlin.

Nathaniel Bowditch outlived all of his brothers and sisters by nearly 30 years. Death came to him on March 16,

1838, in his sixty-fifth year. The following eulogy by the Salem Marine Society indicates the regard in which this distinguished American was held by his contemporaries:

"In his death a public, a national, a human benefactor has departed. Not this community, nor our country only, but the whole world, has reason to do honor to his memory. When the voice of Eulogy shall be still, when the tear of Sorrow shall cease to flow, no monument will be needed to keep alive his memory among men; but as long as ships shall sail, the needle point to the north, and the stars go through their wonted courses in the heavens, the name of Dr. Bowditch will be revered as of one who helped his fellow-men in a time of need, who was and is a guide to them over the pathless ocean, and of one who forwarded the great interests of mankind."

The New American Practical Navigator was revised by Nathaniel Bowditch several times after 1802 for subsequent editions of the book. After his death, Jonathan Ingersoll Bowditch, a son who made several voyages, took up the work and his name appeared on the title page from the eleventh edition through the thirty-fifth, in 1867. In 1868 the newly organized U.S. Navy Hydrographic Office bought the copyright. Revisions have been made from time to time to keep the work in step with navigational improvements. The name has been altered to the *American Practical Navigator*, but the book is still commonly known as "Bowditch." A total of more than 900,000 copies has been printed in about 75 editions during the nearly two centuries since the book was first published in 1802. It has lived because it has combined the best techniques of each generation of navigators, who have looked to it as their final authority.

THE NEW AMERICAN

PRACTICAL NAVIGATOR;

BEING AN

EPITOME OF NAVIGATION;

CONTAINING ALL THE TABLES NECESSARY TO BE USED WITH THE

NAUTICAL ALMANAC,

IN DETERMINING THE

L A T I T U D E;

AND THE

LONGITUDE BY LUNAR OBSERVATIONS;

AND

KEEPING A COMPLETE RECKONING AT SEA:

ILLUSTRATED BY

PROPER RULES AND EXAMPLES:

THE WHOLE EXEMPLIFIED IN A

J O U R N A L,

KEPT FROM

BOSTON TO MADEIRA,

IN WHICH ALL THE RULES OF NAVIGATION ARE INTRODUCED:

A L S O

The Demonstration of the most useful Rules of Trigonometry: With many useful Problems in Mensuration, Surveying, and Gauging: And a Dictionary of Sea-Terms; with the Manner of performing the most common Evolutions at Sea.

TO WHICH ARE ADDED,

Some General Instructions and Information to Merchants, Masters of Vessels, and others concerned in Navigation, relative to Maritime Laws and Mercantile Customs.

FROM THE BEST AUTHORITIES.

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NEW TABLES,

WITH ORIGINAL IMPROVEMENTS AND ADDITIONS, AND A LARGE VARIETY OF NEW AND IMPORTANT MATTER:

A L S O,

MANY THOUSAND ERRORS ARE CORRECTED,

WHICH HAVE APPEARED IN THE BEST SYSTEMS OF NAVIGATION YET PUBLISHED.

BY NATHANIEL BOWDITCH,

FELLOW OF THE AMERICAN ACADEMY OF ARTS AND SCIENCES.

ILLUSTRATED WITH COPPERPLATES.

First Edition.

PRINTED AT NEWBURYPORT, (Mass.) 1802,

BY

EDMUND M. BLUNT, (Proprietor)

For CUSHING & APPLETON, Salem.

SOLD BY EVERY BOOKSELLER, SHIP-CHANDLER, AND MATHEMATICA[illegible], IN THE UNITED STATES AND WEST-INDIES

Original title page of *The New American Practical Navigator*, First Edition, published in 1802.

PREFACE

The Naval Observatory library in Washington, D.C., is unnaturally quiet. It is a large circular room, filled with thousands of books. Its acoustics are perfect; a mere whisper from the room's open circular balcony can be easily heard by those standing on the ground floor. A fountain in the center of the ground floor softly breaks the room's silence as its water stream slowly splashes into a small pool. A library clerk will lead you into a small antechamber where there is a vault containing the Observatory's most rare books. In this vault, one can find an original 1802 first edition of the *New American Practical Navigator*.

One cannot hold this small, delicate, slipcovered book without being impressed by the nearly 200-year unbroken chain of publication that it has enjoyed. It sailed on U.S. merchantmen shortly after the quasi-war with France and during British impressment of merchant seamen that led to the War of 1812. It sailed on U.S. Naval vessels during operations against Mexico in the 1840's, on ships of both the Union and Confederate fleets during the Civil War, and with the U.S. Navy in Cuba in 1898. It went with the Great White Fleet around the world, across the North Atlantic to Europe during both World Wars, to Asia during the Korean and Vietnam Wars, and to the Middle East during Operation Desert Storm.

As navigational requirements and procedures have changed throughout the years, *Bowditch* has changed with them. Originally devoted almost exclusively to celestial navigation, it now also covers a host of modern topics. It is as practical today as it was when Nathaniel Bowditch, master of the *Putnam*, gathered the crew on deck and taught them the mathematics involved in calculating lunar distances. It is that practicality that has been the publication's greatest strength. It is that practicality that makes the publication as useful today as it was in the age of sail.

Seafarers have long memories. In no other profession is tradition more closely guarded. Even the oldest and most cynical acknowledge the special bond that connects those who have made their livelihood plying the sea. This bond is not comprised of a single strand; rather, it is a rich and varied tapestry that stretches from the present back to the birth of our nation and its seafaring culture. As this book is a part of that tapestry, it should not be lightly regarded; rather, it should be preserved, as much for its historical importance as for its practical utility.

Since antiquity, mariners have gathered available navigation information and put it into a text for others to follow. One of the first attempts at this involved volumes of Spanish and Portuguese navigational manuals translated into English between about 1550 to 1750. Writers and translators of the time "borrowed" freely in compiling navigational texts, a practice which continues today with works such as Sailing Directions and Pilots.

Colonial and early American navigators depended exclusively on English navigation texts because there were no American editions. The first American navigational text, *Orthodoxal Navigation*, was completed by Benjamin Hubbard in 1656. The first American navigation text published in America was Captain Thomas Truxton's *Remarks, Instructions, and Examples Relating to the Latitude and Longitude; also the Variation of the Compass, Etc., Etc.*, published in 1794.

The most popular navigational text of the late 18th century was John Hamilton Moore's *The New Practical Navigator*. Edmund M. Blunt, a Newburyport publisher, decided to issue a revised copy of this work for American navigators. Blunt convinced Nathaniel Bowditch, a locally famous mariner and mathematician, to revise and update *The New Practical Navigator*. Several other men also assisted in the revision. Blunt's *The New Practical Navigator* was published in 1799. Blunt also published a second American edition of Hamilton's book in 1800.

By 1802, when Blunt was ready to publish a third edition, Nathaniel Bowditch and others had corrected so many errors in Hamilton's work that Blunt decided to issue the work as a first edition of the *New American Practical Navigator*. It is to that 1802 work that the current edition of the *American Practical Navigator* traces its pedigree.

The *New American Practical Navigator* stayed in the Bowditch and Blunt family until the government bought the copyright in 1867. Edmund M. Blunt published the book until 1833; upon his retirement, his sons, Edmund and George, took over publication.The elder Blunt died in 1862; his son Edmund followed in 1866. The next year, 1867, George Blunt sold the copyright to the government for $25,000. The government has published *Bowditch* ever since. George Blunt died in 1878.

Nathaniel Bowditch continued to correct and revise the book until his death in 1838. Upon his death, the editorial responsibility for the *American Practical Navigator* passed to his son, J. Ingersoll Bowditch. Ingersoll Bowditch continued editing the *Navigator* until George Blunt sold the copyright to the government. He outlived all of the principals involved in publishing and editing the *Navigator*, dying in 1889.

The U.S. government has published some 52 editions since acquiring the copyright to the book that has come to be known simply by its original author's name, "*Bowditch*". Since the government began production, the book has been known by its year of publishing, instead of by the edi-

tion number. During a revision in 1880 by Commander Phillip H. Cooper, USN, the name was changed to *American Practical Navigator*. Bowditch's original method of taking "lunars" was finally dropped from the book in 1914. After several more minor revisions and printings, *Bowditch* was extensively revised between 1946 and 1958.

The present volume, while retaining the basic format of the 1958 version, reorganizes the subjects, deletes obsolete text, and adds new material to keep pace with the extensive changes in navigation that have taken place in the electronic age.

This 1995 edition of the *American Practical Navigator* incorporates extensive changes in organization, format, and content. Recent advances in navigational electronics, communications, positioning, and other technologies have transformed the way navigation is practiced at sea, and it is clear that even more changes are forthcoming. The changes to this edition of BOWDITCH are intended to ensure that this publication remains the premier reference work for practical marine navigation. Concerted efforts were made to return to Nathaniel Bowditch's original intention "to put down in the book nothing I can't teach the crew." To this end, many complex formulas and equations have been eliminated, and emphasis placed on the capabilities and limitations of various navigation systems and how to use them, instead of explaining complex technical and theoretical details. This edition replaces but does not cancel former editions, which may be retained and consulted as to navigation methods not discussed herein.

The former Volume II has been incorporated into this volume to save space and production cost. A larger page size has also been chosen for similar reasons. These two changes allow us to present a single, comprehensive navigation science reference which explains modern navigational methods while respecting traditional ones. The goal of the changes is to put as much useful information before the navigator as possible in the most understandable and readable format.

TAB 1, FUNDAMENTALS, has been reorganized to include an overview of the types and phases of marine navigation and the organizations which support and regulate it. It includes chapters relating to the structure, use and limitations of nautical charts; chart datums and their importance; and other material of a basic nature. The former chapter on the history of navigation has been largely removed. Historical facts are included in the text where necessary to explain present practices or conventions.

TAB 2, PILOTING, now emphasizes the practical aspects of navigating a vessel in restricted waters.

TAB 3, ELECTRONIC NAVIGATION, returns to the position it held in the 1958 edition. Electronic systems are now the primary means of positioning of the modern navigator. Chapters deal with each of the several electronic methods of navigation, organized by type.

TAB 4, CELESTIAL NAVIGATION, has been streamlined and updated. The text in this section contains updated examples and problems and a completely re-edited sight reduction chapter. Extracts from necessary tables have been added to the body of the text for easier reference.

TAB 5, NAVIGATIONAL MATHEMATICS, includes chapters relating to such topics as basic navigational mathematics and computer use in the solution of navigation problems.

TAB 6, NAVIGATIONAL SAFETY, discusses aspects of the new distress and safety communications systems now in place or being implemented in the next several years, as well as navigation regulations, emergency navigation procedures, and distress communications.

TAB 7, OCEANOGRAPHY, is updated and consolidated, but largely unchanged from the former edition.

TAB 8, MARINE METEOROLOGY, (formerly WEATHER) incorporates new weather routing and forecasting methods and material from former appendices. Included are new color plates of the Beaufort Sea States (Courtesy of Environment Canada).

The Glossary has been extensively edited and updated with modern navigational terms, including computer terminology.

This edition was produced largely electronically from start to finish, using the latest in publishing software and data transfer techniques to provide a very flexible production system. This ensures not only that this book is the most efficiently produced ever, but also that it can be easily updated and improved when it again becomes dated, as it surely will.

The masculine pronoun "he" used throughout is meant to refer to both genders.

This book may be kept corrected using the Notice to Mariners and Summary of Corrections. Suggestions and comments for changes and additions may be sent to:

MARINE NAVIGATION DEPARTMENT
ST D 44
NATIONAL IMAGERY AND MAPPING AGENCY
4600 SANGAMORE ROAD
BETHESDA, MD 20816-5003

This book could not have been produced without the expertise of dedicated personnel from many organizations, among them: U.S. Coast Guard, U.S. Naval Academy, U.S. Naval Oceanographic Office, Fleet Training Center (Norfolk), Fleet Numerical Meteorology and Oceanography Center (Monterey), the U.S. Naval Observatory, U.S. Merchant Marine Academy, U.S. Coast and Geodetic Survey, the National Ocean Service, and the National Weather Service. In addition to official government expertise, we appreciate the contributions of private organizations, in particular the Institute of Navigation, and other organizations and individuals too numerous to mention by name. Mariners worldwide can be grateful for the experience, dedication, and professionalism of the people who generously gave their time in this effort.

THE EDITORS

CHAPTER 1

INTRODUCTION TO MARINE NAVIGATION

DEFINITIONS

100. The Art And Science Of Navigation

Marine navigation blends both science and art. A good navigator gathers information from every available source, evaluates this information, determines a fix, and compares that fix with his pre-determined "dead reckoning" position. A navigator constantly evaluates the ship's position, anticipates dangerous situations well before they arise, and always keeps "ahead of the vessel." The modern navigator must also understand the basic concepts of the many navigation systems used today, evaluate their output's accuracy, and arrive at the best possible navigational decisions.

Navigation methods and techniques vary with the type of vessel, the conditions, and the navigator's experience. Navigating a pleasure craft, for example, differs from navigating a container ship. Both differ from navigating a naval vessel. The navigator uses the methods and techniques best suited to the vessel and conditions at hand.

Some important elements of successful navigation cannot be acquired from any book or instructor. The *science* of navigation can be taught, but the *art* of navigation must be developed from experience.

101. Types Of Navigation

Methods of navigation have changed through history. Each new method has enhanced the mariner's ability to complete his voyage safely and expeditiously. One of the most important judgments the navigator must make involves choosing the best method to use. Commonly recognized types of navigation are listed below.

- **Dead reckoning (DR)** determines position by advancing a known position for courses and distances. A position so determined is called a dead reckoning (DR) position. It is generally accepted that only course and speed determine the DR position. Correcting the DR position for leeway, current effects, and steering error result in an **estimated position (EP)**. An inertial navigator develops an extremely accurate EP.

- **Piloting** involves navigating in restricted waters with frequent determination of position relative to geographic and hydrographic features.

- **Celestial navigation** involves reducing celestial measurements to lines of position using tables, spherical trigonometry, and almanacs. It is used primarily as a backup to satellite and other electronic systems in the open ocean.

- **Radio navigation** uses radio waves to determine position by either radio direction finding systems or hyperbolic systems.

- **Radar navigation** uses radar to determine the distance from or bearing of objects whose position is known. This process is separate from radar's use as a collision avoidance system.

- **Satellite navigation** uses artificial earth satellites for determination of position.

Electronic integrated bridge concepts are driving future navigation system planning. Integrated systems take inputs from various ship sensors, electronically display positioning information, and provide control signals required to maintain a vessel on a preset course. The navigator becomes a system manager, choosing system presets, interpreting system output, and monitoring vessel response.

In practice, a navigator synthesizes different methodologies into a single integrated system. He should never feel comfortable utilizing only one method when others are available for backup. Each method has advantages and disadvantages. The navigator must choose methods appropriate to each particular situation.

With the advent of automated position fixing and electronic charts, modern navigation is almost completely an electronic process. The mariner is constantly tempted to rely solely on electronic systems. This would be a mistake. Electronic navigation systems are always subject to failure, and the professional mariner must never forget that the safety of his ship and crew may depend on skills that differ little from those practiced generations ago. Proficiency in conventional piloting and celestial navigation remains essential.

102. Phases Of Navigation

Four distinct phases define the navigation process. The

mariner should choose the system mix that meets the accuracy requirements of each phase.

- **Inland Waterway Phase**: Piloting in narrow canals, channels, rivers, and estuaries.
- **Harbor/Harbor Approach Phase**: Navigating to a harbor entrance and piloting in harbor approach channels.
- **Coastal Phase**: Navigating within 50 miles of the coast or inshore of the 200 meter depth contour.
- **Ocean Phase**: Navigating outside the coastal area in the open sea.

The navigator's position accuracy requirements, his fix interval, and his systems requirements differ in each phase. The following table can be used as a general guide for selecting the proper system(s).

	Inland Waterway	*Harbor/Harbor Approach*	*Coastal*	*Ocean*
DR	X	X	X	X
Piloting	X	X	X	
Celestial			X	X
Radio		X	X	X
Radar	X	X	X	
Satellite	X*	X	X	X

Table 102. The relationship of the types and phases of navigation.
* Differential GPS may be used if available.

NAVIGATIONAL TERMS AND CONVENTIONS

103. Important Conventions And Concepts

Throughout the history of navigation, numerous terms and conventions have been established which enjoy worldwide recognition. The professional navigator, to gain a full understanding of his field, should understand the origin of certain terms, techniques, and conventions. The following section discusses some of the important ones.

Defining a **prime meridian** is a comparatively recent development. Until the beginning of the 19th century, there was little uniformity among cartographers as to the meridian from which to measure longitude. This did not lead to any problem because there was no widespread method for determining longitude accurately.

Ptolemy, in the 2nd century AD, measured longitude eastward from a reference meridian 2 degrees west of the Canary Islands. In 1493, Pope Alexander VI established a line in the Atlantic west of the Azores to divide the territories of Spain and Portugal. For many years, cartographers of these two countries used this dividing line as the prime meridian. In 1570 the Dutch cartographer Ortelius used the easternmost of the Cape Verde Islands. John Davis, in his 1594 *The Seaman's Secrets,* used the Isle of Fez in the Canaries because there the variation was zero. Mariners paid little attention to these conventions and often reckoned their longitude from several different capes and ports during a voyage.

The meridian of London was used as early as 1676, and over the years its popularity grew as England's maritime interests increased. The system of measuring longitude both east and west through 180° may have first appeared in the middle of the 18th century. Toward the end of that century, as the Greenwich Observatory increased in prominence, English cartographers began using the meridian of that observatory as a reference. The publication by the Observatory of the first British Nautical Almanac in 1767 further entrenched Greenwich as the prime meridian. An unsuccessful attempt was made in 1810 to establish Washington, D.C. as the prime meridian for American navigators and cartographers. In 1884, the meridian of Greenwich was officially established as the prime meridian. Today, all maritime nations have designated the Greenwich meridian the prime meridian, except in a few cases where local references are used for certain harbor charts.

Charts are graphic representations of areas of the earth for use in marine or air navigation. Nautical charts depict features of particular interest to the marine navigator. Charts have probably existed since at least 600 BC. Stereographic and orthographic projections date from the 2nd century BC. In 1569 Gerardus Mercator published a chart

using the mathematical principle which now bears his name. Some 30 years later, Edward Wright published corrected mathematical tables for this projection, enabling cartographers to produce charts on the Mercator projection. This projection is still widely in use.

Sailing directions or **pilots** have existed since at least the 6th century BC. Continuous accumulation of navigational data, along with increased exploration and trade, led to increased production of volumes through the Middle Ages. “Routiers” were produced in France about 1500; the English referred to them as “rutters.” In 1584 Lucas Waghenaer published the *Spieghel der Zeevaerdt (The Mariner’s Mirror)*, which became the model for such publications for several generations of navigators. They were known as “Waggoners” by most sailors. Modern pilots and sailing directions are based on extensive data collection and compilation efforts begun by Matthew Fontaine Maury beginning in 1842.

The **compass** was developed about 1000 years ago. The origin of the magnetic compass is uncertain, but Norsemen used it in the 11th century. It was not until the 1870s that Lord Kelvin developed a reliable dry card marine compass. The fluid-filled compass became standard in 1906.

Variation was not understood until the 18th century, when Edmond Halley led an expedition to map lines of variation in the South Atlantic. **Deviation** was understood at least as early as the early 1600s, but correction of compass error was not possible until Matthew Flinders discovered that a vertical iron bar could reduce errors. After 1840, British Astronomer Royal Sir George Airy and later Lord Kelvin developed combinations of iron masses and small magnets to eliminate most magnetic compass error.

The **gyrocompass** was made necessary by iron and steel ships. Leon Foucault developed the basic gyroscope in 1852. An American (Elmer Sperry) and a German (Anshutz Kampfe) both developed electrical gyrocompasses in the early years of the 20th century.

The **log** is the mariner’s speedometer. Mariners originally measured speed by observing a chip of wood passing down the side of the vessel. Later developments included a wooden board attached to a reel of line. Mariners measured speed by noting how many knots in the line unreeled as the ship moved a measured amount of time; hence the term **knot.** Mechanical logs using either a small paddle wheel or a rotating spinner arrived about the middle of the 17th century. The taffrail log still in limited use today was developed in 1878. Modern logs use electronic sensors or spinning devices that induce small electric fields proportional to a vessel’s speed. An engine revolution counter or shaft log often measures speed onboard large ships. Doppler speed logs are used on some vessels for very accurate speed readings. Inertial and satellite systems also provide highly accurate speed readings.

The Metric Conversion Act of 1975 and the Omnibus Trade and Competitiveness Act of 1988 established the **metric system** of weights and measures in the United States. As a result, the government is converting charts to the metric format. Considerations of expense, safety of navigation, and logical sequencing will require a conversion effort spanning many years. Notwithstanding the conversion to the metric system, the common measure of distance at sea is the **nautical mile**.

The current policy of the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) and the National Ocean Service (NOS) is to convert new compilations of nautical, special purpose charts, and publications to the metric system. This conversion began on January 2, 1970. Most modern maritime nations have also adopted the meter as the standard measure of depths and heights. However, older charts still on issue and the charts of some foreign countries may not conform to this standard.

The **fathom** as a unit of length or depth is of obscure origin. Posidonius reported a sounding of more than 1,000 fathoms in the 2nd century BC. How old the unit was then is unknown. Many modern charts are still based on the fathom, as conversion to the metric system continues.

The sailings refer to various methods of mathematically determining course, distance, and position. They have a history almost as old as mathematics itself. Thales, Hipparchus, Napier, Wright, and others contributed the formulas that permit computation of course and distance by plane, traverse, parallel, middle latitude, Mercator, and great circle sailings.

104. The Earth

The earth is an oblate spheroid (a sphere flattened at the poles). Measurements of its dimensions and the amount of its flattening are subjects of geodesy. However, for most navigational purposes, assuming a spherical earth introduces insignificant error. The earth’s axis of rotation is the line connecting the North Pole and the South Pole.

A **great circle** is the line of intersection of a sphere and a plane through its center. This is the largest circle that can be drawn on a sphere. The shortest line on the surface of a sphere between two points on the surface is part of a great circle. On the spheroidal earth the shortest line is called a **geodesic**. A great circle is a near enough approximation to a geodesic for most problems of navigation. A **small circle** is the line of intersection of a sphere and a plane which does not pass through the center. See Figure 104a.

The term **meridian** is usually applied to the **upper branch** of the half-circle from pole to pole which passes through a given point. The opposite half is called the **lower branch.**

A **parallel** or parallel of latitude is a circle on the surface of the earth parallel to the plane of the equator. It connects all points of equal latitude. The equator is a great circle at latitude 0°. See Figure 104b. The poles are single points at latitude 90°. All other parallels are small circles.

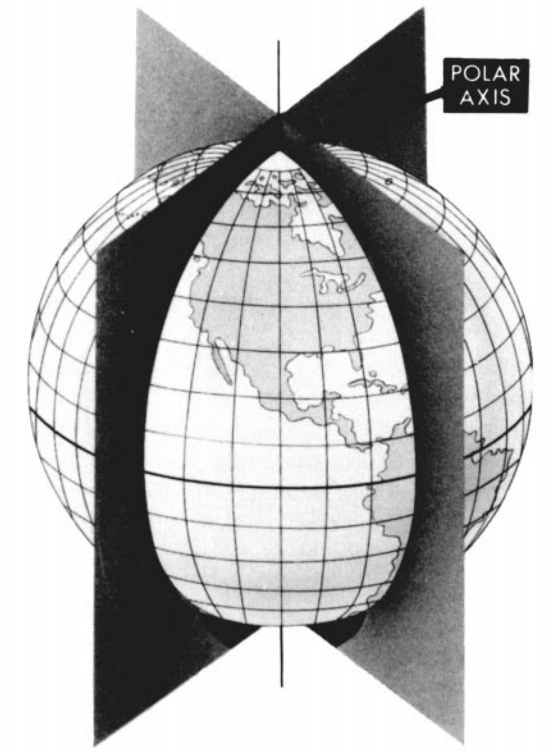


Figure 104a. The planes of the meridians at the polar axis.

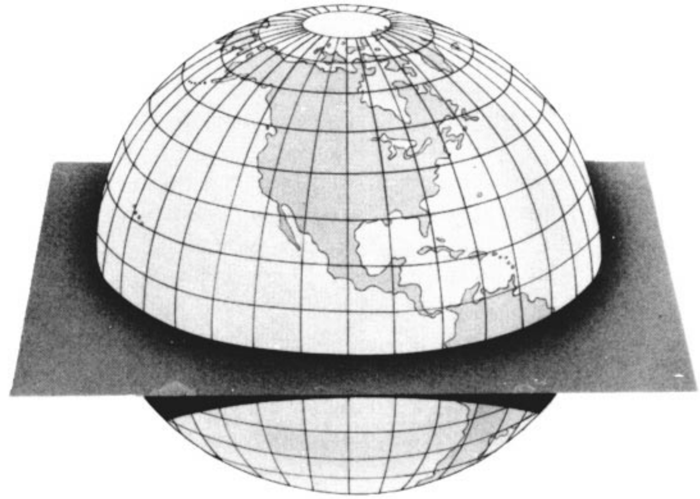


Figure 104b. The equator is a great circle midway between the poles.

105. Coordinates

Coordinates, termed **latitude** and **longitude**, can define any position on earth. **Latitude (L, lat.)** is the angular distance from the equator, measured northward or southward along a meridian from 0° at the equator to 90° at the poles. It is designated north (N) or south (S) to indicate the direction of measurement.

The **difference of latitude (*l*, DLat.)** between two places is the angular length of arc of any meridian between their parallels. It is the numerical difference of the latitudes if the places are on the same side of the equator; it is the sum of the latitudes if the places are on opposite sides of the equator. It may be designated north (N) or south (S) when appropriate. The middle or **mid-latitude (Lm)** between two places on the same side of the equator is half the sum of their latitudes. Mid-latitude is labeled N or S to indicate whether it is north or south of the equator.

The expression may refer to the mid-latitude of two places on opposite sides of the equator. In this case, it is equal to half the difference between the two latitudes and takes the name of the place farthest from the equator. However, this usage is misleading because it lacks the significance usually associated with the expression. When the places are on opposite sides of the equator, two mid-latitudes are generally used. Calculate these two mid-latitudes by averaging each latitude and 0°.

Longitude (l, long.) is the angular distance between the prime meridian and the meridian of a point on the earth, measured eastward or westward from the prime meridian through 180°. It is designated east (E) or west (W) to indicate the direction of measurement.

The **difference of longitude (DLo)** between two places is the shorter arc of the parallel or the smaller angle at the pole between the meridians of the two places. If both places are on the same side (east or west) of Greenwich, DLo is the numerical difference of the longitudes of the two places; if on opposite sides, DLo is the numerical sum unless this exceeds 180°, when it is 360° minus the sum. The distance between two meridians at any parallel of latitude, expressed in distance units, usually nautical miles, is called **departure (p, Dep.)**. It represents distance made good east or west as a craft proceeds from one point to another. Its numerical value between any two meridians decreases with increased latitude, while DLo is numerically the same at any latitude. Either DLo or p may be designated east (E) or west (W) when appropriate.

106. Distance On The Earth

Distance, as used by the navigator, is the length of the **rhumb line** connecting two places. This is a line making the same angle with all meridians. Meridians and parallels which also maintain constant true directions may be con-

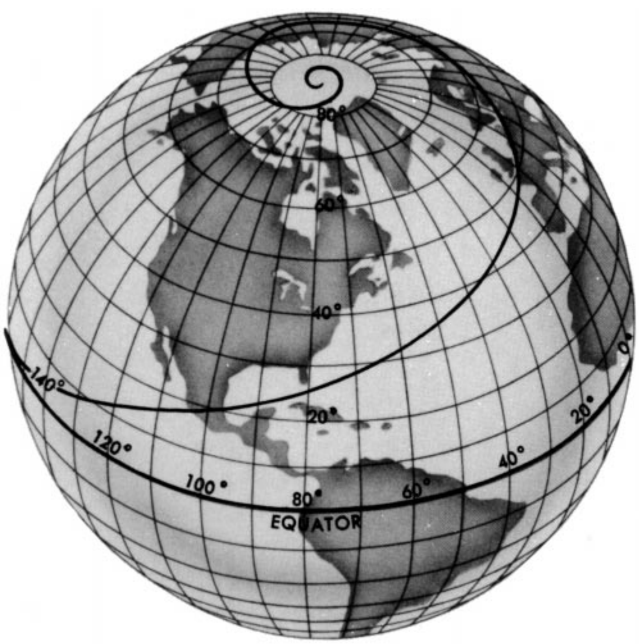


Figure 106. A loxodrome.

sidered special cases of the rhumb line. Any other rhumb line spirals toward the pole, forming a **loxodromic curve** or **loxodrome**. See Figure 106. Distance along the great circle connecting two points is customarily designated **great-circle distance**. For most purposes, considering the nautical mile the length of one minute of latitude introduces no significant error.

Speed (S) is rate of motion, or distance per unit of time. A **knot (kn.)**, the unit of speed commonly used in navigation, is a rate of 1 nautical mile per hour. The expression **speed of advance (SOA)** is used to indicate the speed to be made along the intended track. **Speed over the ground (SOG)** is the actual speed of the vessel over the surface of the earth at any given time. To calculate **speed made good (SMG)** between two positions, divide the distance between the two positions by the time elapsed between the two positions.

107. Direction On The Earth

Direction is the position of one point relative to another. Navigators express direction as the angular difference in degrees from a reference direction, usually north or the ship's head. **Course (C, Cn)** is the horizontal direction in which a vessel is steered or intended to be steered, expressed as angular distance from north clockwise through 360°. Strictly used, the term applies to direction through the water, not the direction intended to be made good over the ground.

The course is often designated as true, magnetic, compass, or grid according to the reference direction. **Track made good (TMG)** is the single resultant direction from the point of departure to point of arrival at any given time. **Course of advance (COA)** is the direction intended to be made good over the ground, and **course over ground (COG)** is the direction between a vessel's last fix and an EP. A course line is a line drawn on a chart extending in the direction of a course. It is sometimes convenient to express a course as an angle from either north or south, through 90° or 180°. In this case it is designated course angle (C) and should be properly labeled to indicate the origin (prefix) and direction of measurement (suffix). Thus, C N35°E = Cn 035° (000° + 35°), C N155°W = Cn 205° (360° - 155°), C S47°E = Cn 133° (180° - 47°). But Cn 260° may be either C N100°W or C S80°W, depending upon the conditions of the problem.

Track (TR) is the intended horizontal direction of travel with respect to the earth. The terms intended track and trackline are used to indicate the path of intended travel. See Figure 107a. The track consists of one or a series of course lines, from the point of departure to the destination, along which it is intended to proceed. A great circle which a vessel intends to follow is called a **great-circle track**, though it consists of a series of straight lines approximating a great circle.

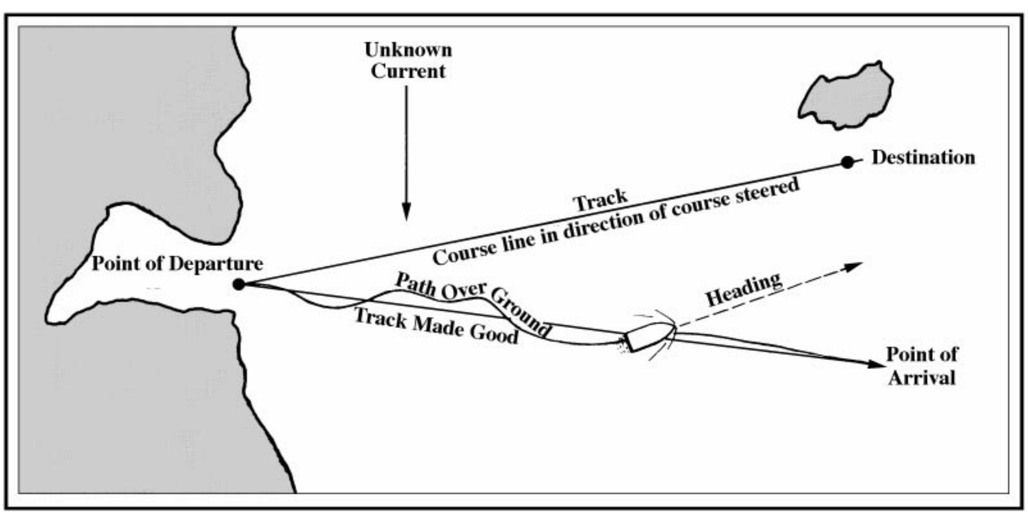


Figure 107a. Course line, track, track made good, and heading.

Heading (Hdg., SH) is the direction in which a vessel is pointed, expressed as angular distance from 000° clockwise through 360°. Do not confuse heading and course. Heading constantly changes as a vessel yaws back and forth across the course due to sea, wind, and steering error.

Bearing (B, Brg.) is the direction of one terrestrial point from another, expressed as angular distance from 000° (North) clockwise through 360°. When measured through 90° or 180° from either north or south, it is called bearing angle (B). Bearing and azimuth are sometimes used interchangeably, but the latter more accurately refers to the horizontal direction of a point on the celestial sphere from a point on the earth. A relative bearing is measured relative to the ship's heading from 000° (dead ahead) clockwise through 360°. However, it is sometimes conveniently measured right or left from 0° at the ship's head through 180°. This is particularly true when using the table for Distance of an Object by Two Bearings.

To convert a relative bearing to a true bearing, add the true heading:

True Bearing = Relative Bearing + True Heading.
Relative Bearing = True Bearing – True Heading.

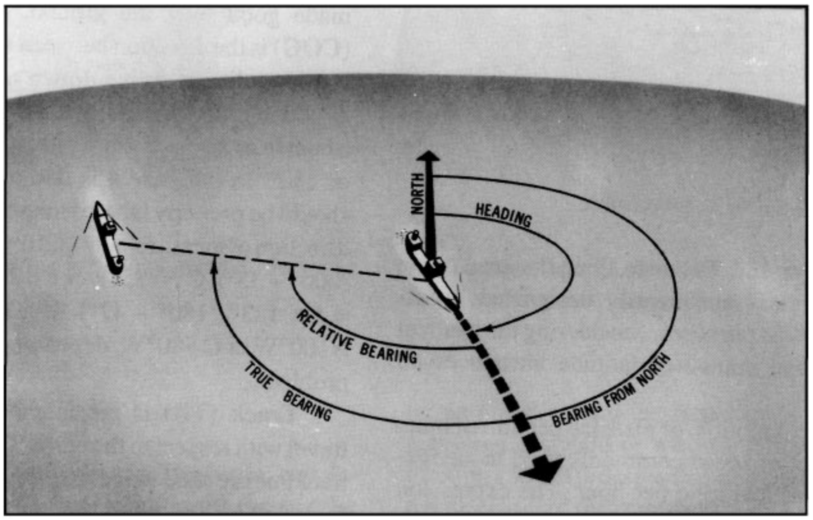


Figure 107b. Relative Bearing.

DEVELOPMENT OF NAVIGATION

108. Latitude And Longitude Determination

Navigators have made latitude observations for thousands of years. Accurate sun declination tables have been published for centuries, enabling experienced seamen to compute latitude to within 1 or 2 degrees. Mariners still use meridian observations of the sun and highly refined ex-meridian techniques. Those who today determine their latitude by measuring the altitude of Polaris are using a method well known to 15th century navigators.

A method of finding longitude eluded mariners for centuries. Several solutions independent of time proved too cumbersome. The lunar distance method, which determines GMT by observing the moon's position among the stars, became popular in the 1800s. However, the mathematics required by most of these processes were far above the abilities of the average seaman. It was apparent that the solution lay in keeping accurate time at sea.

In 1714, the British Board of Longitude was formed, offering a small fortune in reward to anyone who could provide a solution to the problem.

An Englishman, John Harrison, responded to the challenge, developing four chronometers between 1735 and 1760. The most accurate of these timepieces lost only 15 seconds on a 156 day round trip between London and Barbados. The Board, however, paid him only half the promised reward. The King finally intervened on Harrison's behalf, and Harrison received his full reward of £20,000 at the advanced age of 80.

Rapid chronometer development led to the problem of determining **chronometer error** aboard ship. **Time balls**, large black spheres mounted in port in prominent locations, were dropped at the stroke of noon, enabling any ship in harbor which could see the ball to determine chronometer error. By the end of the U.S. Civil War, telegraph signals were being used to key time balls. Use of radio signals to send time ticks to ships well offshore began in 1904, and soon worldwide signals were available.

109. The Navigational Triangle

Modern celestial navigators reduce their celestial observations by solving a **navigational triangle** whose points are the elevated pole, the celestial body, and the zenith of the observer. The sides of this triangle are the polar distance of the body (**codeclination**), its zenith distance (**coaltitude**), and the polar distance of the zenith (**colatitude** of the observer).

A spherical triangle was first used at sea in solving **lunar distance** problems. Simultaneous observations were made of the altitudes of the moon and the sun or a star near the ecliptic and the angular distance between the moon and the other body. The zenith of the observer and the two celestial bodies formed the vertices of a triangle whose sides were the two coaltitudes and the angular distance between the bodies. Using a mathematical calculation the navigator "cleared" this distance of the effects of refraction and parallax applicable to each altitude. This corrected value was then used as an argument for entering the almanac. The almanac gave the true lunar distance from the sun and several stars at 3 hour intervals. Previously, the navigator had set his watch or checked its error and rate with the local mean time determined by celestial observations. The local mean time of the watch, properly corrected, applied to the Greenwich mean time obtained from the lunar distance observation, gave the longitude.

The calculations involved were tedious. Few mariners could solve the triangle until Nathaniel Bowditch published his simplified method in 1802 in *The New American Practical Navigator*.

Reliable chronometers were available in 1802, but their high cost precluded their general use aboard most ships. However, most navigators could determine their longitude using Bowditch's method. This eliminated the need for parallel sailing and the lost time associated with it. Tables for the lunar distance solution were carried in the American nautical almanac until the second decade of the 20th century.

110. The Time Sight

The theory of the **time sight** had been known to mathematicians since the development of spherical trigonometry, but not until the chronometer was developed could it be used by mariners.

The time sight used the modern navigational triangle. The codeclination, or polar distance, of the body could be determined from the almanac. The zenith distance (coaltitude) was determined by observation. If the colatitude were known, three sides of the triangle were available. From these the meridian angle was computed. The comparison of this with the Greenwich hour angle from the almanac yielded the longitude.

The time sight was mathematically sound, but the navigator was not always aware that the longitude determined was only as accurate as the latitude, and together they merely formed a point on what is known today as a **line of position**. If the observed body was on the prime vertical, the line of position ran north and south and a small error in latitude generally had little effect on the longitude. But when the body was close to the meridian, a small error in latitude produced a large error in longitude.

The line of position by celestial observation was unknown until discovered in 1837 by 30-year-old Captain Thomas H. Sumner, a Harvard graduate and son of a United States congressman from Massachusetts. The discovery of the "**Sumner line**," as it is sometimes called, was considered by Maury "the commencement of a new era in practical navigation." This was the turning point in the development of modern celestial navigation technique. In Sumner's own words, the discovery took place in this manner:

> Having sailed from Charleston, S. C., 25th November, 1837, bound to Greenock, a series of heavy gales from the Westward promised a quick passage; after passing the Azores, the wind prevailed from the Southward, with thick weather; after passing Longitude 21° W, no observation was had until near the land; but soundings were had not far, as was supposed, from the edge of the Bank. The weather was now more boisterous, and very thick; and the wind still Southerly; arriving about midnight, 17th December, within 40 miles, by dead reckoning, of Tusker light; the wind hauled SE, true, making the Irish coast a lee shore; the ship was then kept close to the wind, and several tacks made to preserve her position as nearly as possible until daylight; when nothing being in sight, she was kept on ENE under short sail, with heavy gales; at about 10 AM an altitude of the sun was observed, and the Chronometer time noted; but, having run so far without any observation, it was plain the Latitude by dead reckoning was liable to error, and could not be entirely relied on. Using, however, this Latitude, in finding the Longitude by Chronometer, it was found to put the ship 15' of Longitude E from her position by dead reckoning; which in Latitude 52° N is 9 nautical miles; this seemed to agree tolerably well with the dead reckoning; but feeling doubtful of the Latitude, the observation was tried with a Latitude 10' further N, finding this placed the ship ENE 27 nautical miles, of the former position, it was tried again with a Latitude 20' N of the dead reckoning; this also placed the ship still further ENE, and still 27 nautical miles further; these three positions were then seen to lie in the direction of Small's light.
>
> It then at once appeared that the observed altitude must have happened at all the three points, and at Small's light, and at the ship, at the same instant of time; and it followed, that Small's light must bear ENE, if the Chronometer was right. Having been convinced of this truth, the ship was kept on her course, ENE, the wind being still SE., and in less than an hour, Small's light was made bearing ENE 1/2 E, and close aboard.

In 1843 Sumner published a book, A *New and Accurate Method of Finding a Ship's Position at Sea by Projection on Mercator's Chart*. He proposed solving a single time sight

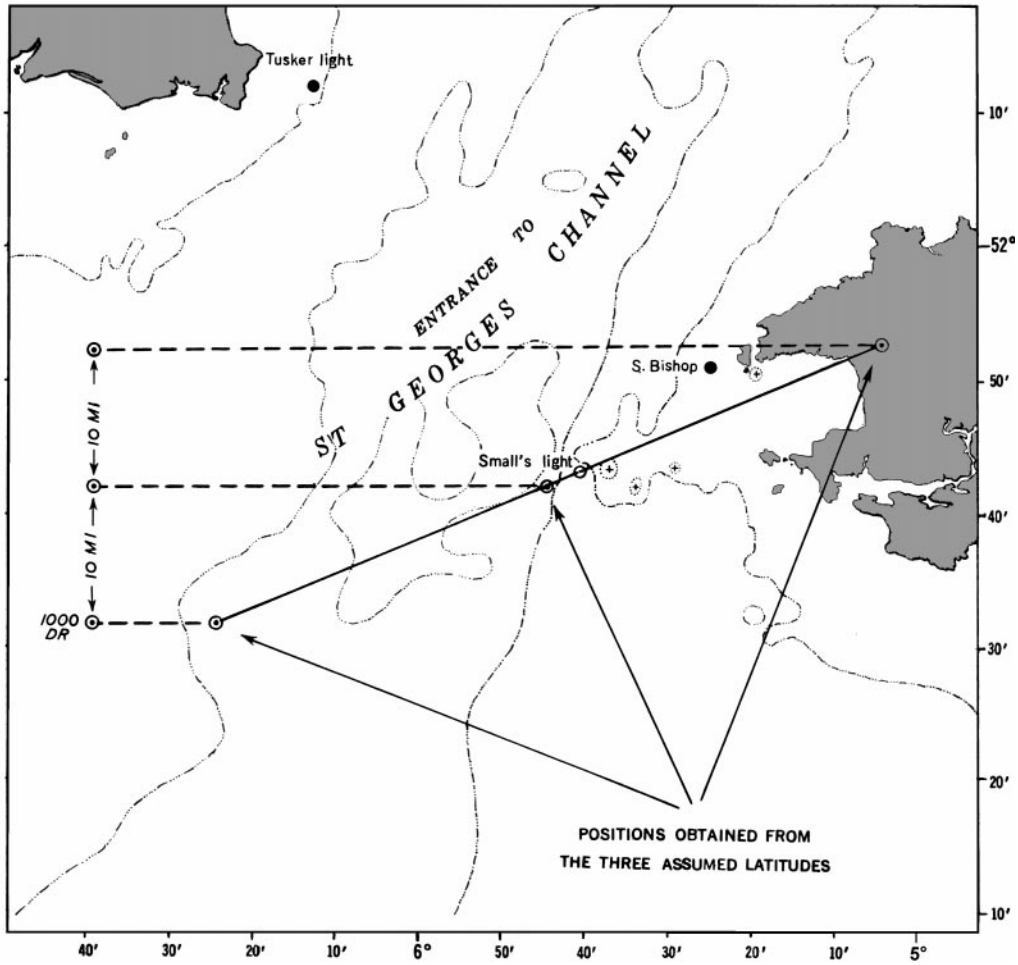


Figure 110. The first celestial line of position, obtained by Captain Thomas Sumner in 1837.

twice, using latitudes somewhat greater and somewhat less than that arrived at by dead reckoning, and joining the two positions obtained to form the line of position.

The Sumner method required the solution of two time sights to obtain each line of position. Many older navigators preferred not to draw the lines on their charts, but to fix their position mathematically by a method which Sumner had also devised and included in his book. This was a tedious but popular procedure.

111. Navigational Tables

Spherical trigonometry is the basis for solving every navigational triangle, and until about 80 years ago the navigator had no choice but to solve each triangle by tedious, manual computations.

Lord Kelvin, generally considered the father of modern navigational methods, expressed interest in a book of tables with which a navigator could avoid tedious trigonometric solutions. However, solving the many thousands of triangles involved would have made the project too costly. Computers finally provided a practical means of preparing tables. In 1936 the first volume of Pub. No. 214 was made available; later, Pub. No. 249 was provided for air navigators. Pub. No. 229, *Sight Reduction Tables for Marine Navigation*, has replaced Pub. No. 214.

Modern calculators are gradually replacing the tables. Scientific calculators with trigonometric functions can easily solve the navigational triangle. Navigational calculators readily solve celestial sights and perform a variety of voyage planning functions. Using a calculator generally gives more accurate lines of position because it eliminates the rounding errors inherent in tabular inspection and interpolation.

112. Electronics And Navigation

Perhaps the first application of electronics to navigation involved sending telegraphic time signals in 1865 to check chronometer error. Transmitting radio time signals for at sea chronometer checks dates to 1904.

Radio broadcasts providing navigational warnings, begun in 1907 by the U.S. Navy Hydrographic Office, helped increase the safety of navigation at sea.

By the latter part of World War I the directional properties of a loop antenna were successfully used in the radio

direction finder. The first radiobeacon was installed in 1921. Early 20th century experiments by Behm and Langevin led to the U.S. Navy's development of the first practical echo sounder in 1922.

Today, electronics touches almost every aspect of navigation. Hyperbolic systems, satellite systems, and electronic charts all require an increasingly sophisticated electronics suite. These systems' accuracy and ease of use make them invaluable assets to the navigator. Indeed, it is no exaggeration to state that, with the advent of the electronic chart and differential GPS, the mariner will soon be able to navigate from port to port using electronic navigation equipment alone.

113. Development Of Radar

As early as 1904, German engineers were experimenting with reflected radio waves. In 1922 two American scientists, Dr. A. Hoyt Taylor and Leo C. Young, testing a communication system at the Naval Aircraft Radio Laboratory, noted fluctuations in the signals when ships passed between stations on opposite sides of the Potomac River. In 1935 the British began work on radar. In 1937 the USS Leary tested the first seagoing radar. In 1940 United States and British scientists combined their efforts. When the British revealed the principle of the multicavity magnetron developed by J. T. Randall and H. A. H. Boot at the University of Birmingham in 1939, microwave radar became practical. In 1945, at the close of World War II, radar became available for commercial use.

114. Development Of Hyperbolic Radio Aids

Various hyperbolic systems were developed from World War II, including Loran A. This was replaced by the more accurate Loran C system in use today. Using very low frequencies, the Omega navigation system provides worldwide, though less accurate, coverage for a variety of applications including marine navigation. Various short range and regional hyperbolic systems have been developed by private industry for hydrographic surveying, offshore facilities positioning, and general navigation.

115. Other Electronic Systems

The **Navy Navigation Satellite System (NAVSAT)** fulfilled a requirement established by the Chief of Naval Operations for an accurate worldwide navigation system for all naval surface vessels, aircraft, and submarines. The system was conceived and developed by the Applied Physics Laboratory of The Johns Hopkins University. The underlying concept that led to development of satellite navigation dates to 1957 and the first launch of an artificial satellite into orbit. NAVSAT has been replaced by the far more accurate and widely available **Global Positioning System (GPS)**.

The first **inertial navigation system** was developed in 1942 for use in the V2 missile by the Peenemunde group under the leadership of Dr. Wernher von Braun. This system used two 2-degree-of-freedom gyroscopes and an integrating accelerometer to determine the missile velocity. By the end of World War II, the Peenemunde group had developed a stable platform with three single-degree-of-freedom gyroscopes and an integrating accelerometer. In 1958 an inertial navigation system was used to navigate the USS *Nautilus* under the ice to the North Pole.

NAVIGATION ORGANIZATIONS

116. Governmental Roles

Navigation only a generation ago was an independent process, carried out by the mariner without outside assistance. With compass and charts, sextant and chronometer, he could independently travel anywhere in the world. The increasing use of electronic navigation systems has made the navigator dependent on many factors outside his control. Government organizations fund, operate, and regulate satellites, Loran, and other electronic systems. Governments are increasingly involved in regulation of vessel movements through traffic control systems and regulated areas. Understanding the governmental role in supporting and regulating navigation is vitally important to the mariner. In the United States, there are a number of official organizations which support the interests of navigators. Some have a policy-making role; others build and operate navigation systems. Many maritime nations have similar organizations performing similar functions. International organizations also play a significant role.

117. The Coast And Geodetic Survey

The **U.S. Coast and Geodetic Survey** was founded in 1807 when Congress passed a resolution authorizing a survey of the coast, harbors, outlying islands, and fishing banks of the United States. President Thomas Jefferson appointed Ferdinand Hassler, a Swiss immigrant and professor of mathematics at West Point, the first Director of the "Survey of the Coast." The survey became the "Coast Survey" in 1836.

The approaches to New York were the first sections of the coast charted, and from there the work spread northward and southward along the eastern seaboard. In 1844 the work was expanded and arrangements made to chart simultaneously the gulf and east coasts. Investigation of tidal conditions began, and in 1855 the first tables of tide predictions were published. The California gold rush necessitated

a survey of the west coast. This survey began in 1850, the year California became a state. Coast Pilots, or Sailing Directions, for the Atlantic coast of the United States were privately published in the first half of the 19th century. In 1850 the Survey began accumulating data that led to federally produced Coast Pilots. The 1889 Pacific Coast Pilot was an outstanding contribution to the safety of west coast shipping.

In 1878 the survey was renamed “Coast and Geodetic Survey.” In 1970 the survey became the “National Ocean Survey,” and in 1983 it became the “National Ocean Service.” The Office of Charting and Geodetic Services accomplished all charting and geodetic functions. In 1991 the name was changed back to the original “Coast and Geodetic Survey,” organized under the National Ocean Service along with several other environmental offices. Today it provides the mariner with the charts and coast pilots of all waters of the United States and its possessions, and tide and tidal current tables for much of the world. Its administrative order requires the Coast and Geodetic Survey to plan and direct programs to produce charts and related information for safe navigation of the Nation’s waterways, territorial seas, and national airspace. This work includes all activities related to the National Geodetic Reference System; surveying, charting, and data collection; production and distribution of charts; and research and development of new technologies to enhance these missions.

118. The Defense Mapping Agency

In the first years of the newly formed United States of America, charts and instruments used by the Navy and merchant mariners were left over from colonial days or were obtained from European sources. In 1830 the U.S. Navy established a “Depot of Charts and Instruments” in Washington, D. C. It was a storehouse from which available charts, sailing directions, and navigational instruments were issued to Naval ships. Lieutenant L. M. Goldsborough and one assistant, Passed Midshipman R. B. Hitchcock, constituted the entire staff.

The first chart published by the Depot was produced from data obtained in a survey made by Lieutenant Charles Wilkes, who had succeeded Goldsborough in 1834. Wilkes later earned fame as the leader of a United States expedition to Antarctica. From 1842 until 1861 Lieutenant Matthew Fontaine Maury served as Officer in Charge. Under his command the Depot rose to international prominence. Maury decided upon an ambitious plan to increase the mariner’s knowledge of existing winds, weather, and currents. He began by making a detailed record of pertinent matter included in old log books stored at the Depot. He then inaugurated a hydrographic reporting program among shipmasters, and the thousands of reports received, along with the log book data, were compiled into the “*Wind and Current Chart of the North Atlantic*” in 1847. This is the ancestor of today’s Pilot Chart. The United States instigated an international conference in 1853 to interest other nations in a system of exchanging nautical information. The plan, which was Maury’s, was enthusiastically adopted by other maritime nations. In 1854 the Depot was redesignated the “U.S. Naval Observatory and Hydrographical Office.” In 1861, Maury, a native of Virginia, resigned from the U.S. Navy and accepted a commission in the Confederate Navy at the beginning of the Civil War. This effectively ended his career as a navigator, author, and oceanographer. At war’s end, he fled the country. Maury’s reputation suffered from his embracing the Confederate cause. In 1867, while Maury was still absent from the country to avoid arrest for treason, George W. Blunt, an editor of hydrographic publications, wrote:

> In mentioning what our government has done towards nautical knowledge, I do not allude to the works of Lieutenant Maury, because I deem them worthless. . . . They have been suppressed since the rebellion by order of the proper authorities, Maury’s loyalty and hydrography being alike in quality.

After Maury’s return to the United States in 1868, he served as an instructor at the Virginia Military Institute. He continued at this position until his death in 1873. Since his death, his reputation as one of America’s greatest hydrographers has been restored.

In 1866 Congress separated the Observatory and the Hydrographic Office, broadly increasing the functions of the latter. The Hydrographic Office was authorized to carry out surveys, collect information, and print every kind of nautical chart and publication “for the benefit and use of navigators generally.”

The Hydrographic Office purchased the copyright of ***The New American Practical Navigator*** in 1867. The first Notice to Mariners appeared in 1869. Daily broadcast of navigational warnings was inaugurated in 1907. In 1912, following the sinking of the *Titanic*, the International Ice Patrol was established.

In 1962 the U.S. Navy Hydrographic Office was redesignated the U.S. Naval Oceanographic Office. In 1972 certain hydrographic functions of the latter office were transferred to the **Defense Mapping Agency Hydrographic Center**. In 1978 the **Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC)** assumed hydrographic and topographic chart production functions. DMAHTC provides support to the U.S. Department of Defense and other federal agencies on matters concerning mapping, charting, and geodesy. It continues to fulfill the old Hydrographic Office’s responsibilities to “navigators generally.”

119. The United States Coast Guard

Alexander Hamilton established the **U.S. Coast Guard** as the Revenue Marine, later the Revenue Cutter Service, on August 4, 1790. It was charged with enforcing the customs laws of the new nation. A revenue cutter, the *Harriet Lane*, fired the first shot from a naval unit in the Civil War at Fort Sumter. The Revenue Cutter Service became the U.S. Coast Guard when combined with the Lifesaving Service in 1915. The Lighthouse Service was added in 1939, and the Bureau of Marine Inspection and Navigation was added in 1942. The Coast Guard was transferred from the Treasury Department to the Department of Transportation in 1967.

The primary functions of the Coast Guard include maritime search and rescue, law enforcement, and operation of the nation's aids to navigation system. In addition, the Coast Guard is responsible for port safety and security, merchant marine inspection, and marine pollution control. The Coast Guard operates a large and varied fleet of ships, boats, and aircraft in performing its widely ranging duties.

Navigation systems operated by the Coast Guard include the system of some 40,000 lighted and unlighted beacons, buoys, and ranges in U.S. waters; the U.S. stations of the Loran C system; the Omega navigation system; radiobeacons and racons; differential GPS (DGPS) services in the U.S.; and Vessel Traffic Services (VTS) in major ports and harbors of the U.S.

120. The United States Navy

The **U.S. Navy** was officially established in 1798. Its role in the development of navigational technology has been singular. From the founding of the Naval Observatory to the development of the most advanced electronics, the U.S. Navy has been a leader in developing devices and techniques designed to make the navigator's job safer and easier.

The development of almost every device known to navigation science has been deeply influenced by Naval policy. Some systems are direct outgrowths of specific Naval needs; some are the result of technological improvements shared with other services and with commercial maritime industry.

121. The United States Naval Observatory

One of the first observatories in the United States was built in 1831-1832 at Chapel Hill, N.C. The Depot of Charts and Instruments, established in 1830, was the agency from which the U.S. Navy Hydrographic Office and the **U.S. Naval Observatory** evolved 36 years later. Under Lieutenant Charles Wilkes, the second Officer in Charge, the Depot about 1835 installed a small transit instrument for rating chronometers.

The Mallory Act of 1842 provided for the establishment of a permanent observatory. The director was authorized to purchase everything necessary to continue astronomical study. The observatory was completed in 1844 and the results of its first observations were published two years later. Congress established the Naval Observatory as a separate agency in 1866. In 1873 a refracting telescope with a 26 inch aperture, then the world's largest, was installed. The observatory, located in Washington, D.C., has occupied its present site since 1893.

122. The Royal Greenwich Observatory

England had no early privately supported observatories such as those on the continent. The need for navigational advancement was ignored by Henry VIII and Elizabeth I, but in 1675 Charles II, at the urging of John Flamsteed, Jonas Moore, Le Sieur de Saint Pierre, and Christopher Wren, established the **Greenwich Royal Observatory**. Charles limited construction costs to £500, and appointed Flamsteed the first Astronomer Royal, at an annual salary of £100. The equipment available in the early years of the observatory consisted of two clocks, a "sextant" of 7 foot radius, a quadrant of 3 foot radius, two telescopes, and the star catalog published almost a century before by Tycho Brahe. Thirteen years passed before Flamsteed had an instrument with which he could determine his latitude accurately.

In 1690 a transit instrument equipped with a telescope and vernier was invented by Romer; he later added a vertical circle to the device. This enabled the astronomer to determine declination and right ascension at the same time. One of these instruments was added to the equipment at Greenwich in 1721, replacing the huge quadrant previously used. The development and perfection of the chronometer in the next hundred years added to the accuracy of observations.

Other national observatories were constructed in the years that followed: at Berlin in 1705, St. Petersburg in 1725, Palermo in 1790, Cape of Good Hope in 1820, Parramatta in New South Wales in 1822, and Sydney in 1855.

123. The International Hydrographic Organization

The **International Hydrographic Organization (IHO)** was originally established in 1921 as the International Hydrographic Bureau (IHB). The present name was adopted in 1970 as a result of a revised international agreement among member nations. However, the former name, International Hydrographic Bureau, was retained for the IHO's administrative body of three Directors and a small staff at the organization's headquarters in Monaco.

The IHO sets forth hydrographic standards to be agreed upon by the member nations. All member states are urged and encouraged to follow these standards in their surveys, nautical charts, and publications. As these standards are uniformly adopted, the products of the world's hydrographic and oceanographic offices become more uniform. Much has been done in the field of standardization since the

Bureau was founded.

The principal work undertaken by the IHO is:

- To bring about a close and permanent association between national hydrographic offices.
- To study matters relating to hydrography and allied sciences and techniques.
- To further the exchange of nautical charts and documents between hydrographic offices of member governments.
- To circulate the appropriate documents.
- To tender guidance and advice upon request, in particular to countries engaged in setting up or expanding their hydrographic service.
- To encourage coordination of hydrographic surveys with relevant oceanographic activities.
- To extend and facilitate the application of oceanographic knowledge for the benefit of navigators.
- To cooperate with international organizations and scientific institutions which have related objectives.

During the 19th century, many maritime nations established hydrographic offices to provide means for improving the navigation of naval and merchant vessels by providing nautical publications, nautical charts, and other navigational services. There were substantial differences in hydrographic procedures, charts, and publications. In 1889, an International Marine Conference was held at Washington, D. C., and it was proposed to establish a "permanent international commission." Similar proposals were made at the sessions of the International Congress of Navigation held at St. Petersburg in 1908 and again in 1912.

In 1919 the hydrographers of Great Britain and France cooperated in taking the necessary steps to convene an international conference of hydrographers. London was selected as the most suitable place for this conference, and on July 24, 1919, the First International Conference opened, attended by the hydrographers of 24 nations. The object of the conference was "To consider the advisability of all maritime nations adopting similar methods in the preparation, construction, and production of their charts and all hydrographic publications; of rendering the results in the most convenient form to enable them to be readily used; of instituting a prompt system of mutual exchange of hydrographic information between all countries; and of providing an opportunity to consultations and discussions to be carried out on hydrographic subjects generally by the hydrographic experts of the world." This is still the major purpose of the International Hydrographic Organization.

As a result of the conference, a permanent organization was formed and statutes for its operations were prepared. The International Hydrographic Bureau, now the International Hydrographic Organization, began its activities in 1921 with 18 nations as members. The Principality of Monaco was selected because of its easy communication with the rest of the world and also because of the generous offer of Prince Albert I of Monaco to provide suitable accommodations for the Bureau in the Principality. There are currently 59 member governments. Technical assistance with hydrographic matters is available through the IHO to member states requiring it.

Many IHO publications are available to the general public, such as the International Hydrographic Review, International Hydrographic Bulletin, Chart Specifications of the IHO, Hydrographic Dictionary, and others. Inquiries should be made to the International Hydrographic Bureau, 7 Avenue President J. F. Kennedy, B.P. 445, MC98011, Monaco, CEDEX.

124. The International Maritime Organization

The **International Maritime Organization (IMO)** was established by United Nations Convention in 1948. The Convention actually entered into force in 1959, although an international convention on marine pollution was adopted in 1954. (Until 1982 the official name of the organization was the Inter-Governmental Maritime Consultative Organization.) It is the only permanent body of the U. N. devoted to maritime matters, and the only special U. N. agency to have its headquarters in the UK.

The governing body of the IMO is the **Assembly** of 137 member states, which meets every two years. Between Assembly sessions a Council, consisting of 32 member governments elected by the Assembly, governs the organization. Its work is carried out by the following committees:

- Maritime Safety Committee, with subcommittees for:
- Safety of Navigation
- Radiocommunications
- Life-saving
- Search and Rescue
- Training and Watchkeeping
- Carriage of Dangerous Goods
- Ship Design and Equipment
- Fire Protection
- Stability and Load Lines/Fishing Vessel Safety
- Containers and Cargoes
- Bulk Chemicals
- Marine Environment Protection Committee
- Legal Committee
- Technical Cooperation Committee
- Facilitation Committee

IMO is headed by the Secretary General, appointed by the council and approved by the Assembly. He is assisted by some 300 civil servants.

To achieve its objectives of coordinating international policy on marine matters, the IMO has adopted some 30 conventions and protocols, and adopted over 700 codes and recommendations. An issue to be adopted first is brought before a committee or subcommittee, which submits a draft to a conference. When the conference adopts the final text, it is submitted

to member governments for ratification. Ratification by a specified number of countries is necessary for adoption; the more important the issue, the more countries must ratify. Adopted conventions are binding on member governments.

Codes and recommendations are not binding, but in most cases are supported by domestic legislation by the governments involved.

The first and most far-reaching convention adopted by the IMO was the Convention of **Safety of Life at Sea (SOLAS)** in 1960. This convention actually came into force in 1965, replacing a version first adopted in 1948. Because of the difficult process of bringing amendments into force internationally, none of subsequent amendments became binding. To remedy this situation, a new convention was adopted in 1974, and became binding in 1980. Among the regulations is V-20, requiring the carriage of up-to-date charts and publications sufficient for the intended voyage.

Other conventions and amendments were also adopted, such as the International Convention on Load Lines (adopted 1966, came into force 1968), a convention on the tonnage measurement of ships (adopted 1969, came into force 1982), The International Convention on Safe Containers (adopted 1972, came into force 1977), and the convention on **International Regulations for Preventing Collisions at Sea (COLREGS)** (adopted 1972, came into force 1977).

The 1972 COLREGS convention contained, among other provisions, a section devoted to Traffic Separation Schemes, which became binding on member states after having been adopted as recommendations in prior years.

One of the most important conventions is the **International Convention for the Prevention of Pollution from Ships (MARPOL 73/78)**, which was first adopted in 1973, amended by Protocol in 1978, and became binding in 1983. This convention built on a series of prior conventions and agreements dating from 1954, highlighted by several severe pollution disasters involving oil tankers. The MARPOL convention reduces the amount of oil discharged into the sea by ships, and bans discharges completely in certain areas. A related convention known as the London Dumping Convention regulates dumping of hazardous chemicals and other debris into the sea.

IMO also develops minimum performance standards for a wide range of equipment relevant to safety at sea. Among such standards is one for the **Electronic Chart Display and Information System (ECDIS)**, the digital display deemed the operational and legal equivalent of the conventional paper chart.

Texts of the various conventions and recommendations, as well as a catalog and publications on other subjects, are available from the Publications Section of the IMO at 4 Albert Embankment, London SE1 7SR, United Kingdom.

125. The International Association Of Lighthouse Authorities

The **International Association of Lighthouse Authorities (IALA)** brings together representatives of the aids to navigation services of more than 80 member countries for technical coordination, information sharing, and coordination of improvements to visual aids to navigation throughout the world. It was established in 1957 to provide a permanent organization to support the goals of the Technical Lighthouse Conferences, which had been convening since 1929. The General Assembly of IALA meets about every 4 years. The Council of 20 members meets twice a year to oversee the ongoing programs.

Five technical committees maintain the permanent programs:

- The Marine Marking Committee
- The Radionavigation Systems Committee
- The Vessel Traffic Services (VTS) Committee
- The Reliability Committee
- The Documentation Committee

IALA committees provide important documentation to the IHO and other international organizations, while the IALA Secretariat acts as a clearing house for the exchange of technical information, and organizes seminars and technical support for developing countries.

Its principle work since 1973 has been the implementation of the IALA Maritime Buoyage System, described in Chapter 5, Visual Aids to Navigation. This system replaced some 30 dissimilar buoyage systems in use throughout the world with 2 major systems.

IALA is based near Paris, France in Saint-Germaine-en-Laye.

126. The Radio Technical Commission for Maritime Services

The **Radio Technical Commission for Maritime Services** is a non-profit organization which serves as a focal point for the exchange of information and the development of recommendations and standards related to all aspects of maritime telecommunications.

Specifically, RTCM:

- Promotes ideas and exchanges information on maritime telecommunications.
- Facilitates the development and exchange of views among government, business, and the public.
- Conducts studies and prepares reports on maritime telecommunications issues to improve efficiency and capabilities.
- Suggests minimum essential rules and regulations for effective telecommunications.
- Makes recommendations on important issues.
- Pursues other activities as permitted by its by-laws and membership.

Both government and non-government organizations are members, including many from foreign nations. The or-

ganization consists of a Board of Directors, the Assembly consisting of all Members, Officers, staff, technical advisors, and standing and special committees.

Working committees are formed as needed to develop official RTCM recommendations regarding technical standards and policies in the maritime field. Currently committees exist for maritime safety information, electronic charts, emergency position-indicating radiobeacons (EPIRB's) and personal locator beacons, survival craft telecommunications, differential GPS, and GLONASS. Ad hoc committees address short-term concerns such as regulatory proposals.

RTCM headquarters is in Washington D.C.

127. The National Marine Electronic Association

The **National Marine Electronic Association (NMEA)** is a professional trade association founded in 1957 whose purpose is to coordinate the efforts of marine electronics manufacturers, technicians, government agencies, ship and boat builders, and other interested groups. In addition to certifying marine electronics technicians and professionally recognizing outstanding achievements by corporate and individual members, the NMEA sets standards for the exchange of digital data by all manufacturers of marine electronic equipment. This allows the configuration of integrated navigation system using equipment from different manufacturers.

NMEA works closely with RTCM and other private organizations and with government agencies to monitor the status of laws and regulations affecting the marine electronics industry.

It also sponsors conferences and seminars, and publishes a number of guides and periodicals for members and the general public.

CHAPTER 2

GEODESY AND DATUMS IN NAVIGATION

GEODESY, THE BASIS OF CARTOGRAPHY

200. Definition

Geodesy is the science concerned with the exact positioning of points on the surface of the earth. It also involves the study of variations of the earth's gravity, the application of these variations to exact measurements on the earth, and the study of the exact size and shape of the earth. These factors were unimportant to early navigators because of the relative inaccuracy of their methods. The precise accuracies of today's navigation systems and the global nature of satellite and other long-range positioning methods demand a more complete understanding of geodesy than has ever before been required.

201. The Shape Of The Earth

The irregular **topographic surface** is that upon which actual geodetic measurements are made. The measurements, however, are reduced to the **geoid**. Marine navigation measurements are made on the ocean surface which approximates the geoid.

The **geoid** is a surface along which gravity is always equal and to which the direction of gravity is always perpendicular. The latter is particularly significant because optical instruments containing level devices are commonly used to make geodetic measurements. When properly adjusted, the vertical axis of the instrument coincides with the direction of gravity and is, therefore, perpendicular to the geoid.

The geoid is that surface to which the oceans would conform over the entire earth if free to adjust to the combined effect of the earth's mass attraction and the centrifugal force of the earth's rotation. The ideal ocean surface would be free of ocean currents and salinity changes. Uneven distribution of the earth's mass makes the geoidal surface irregular.

The geoid refers to the actual size and shape of the earth, but such an irregular surface has serious limitations as a mathematical earth model because:

- It has no complete mathematical expression.
- Small variations in surface shape over time introduce small errors in measurement.
- The irregularity of the surface would necessitate a prohibitive amount of computations.

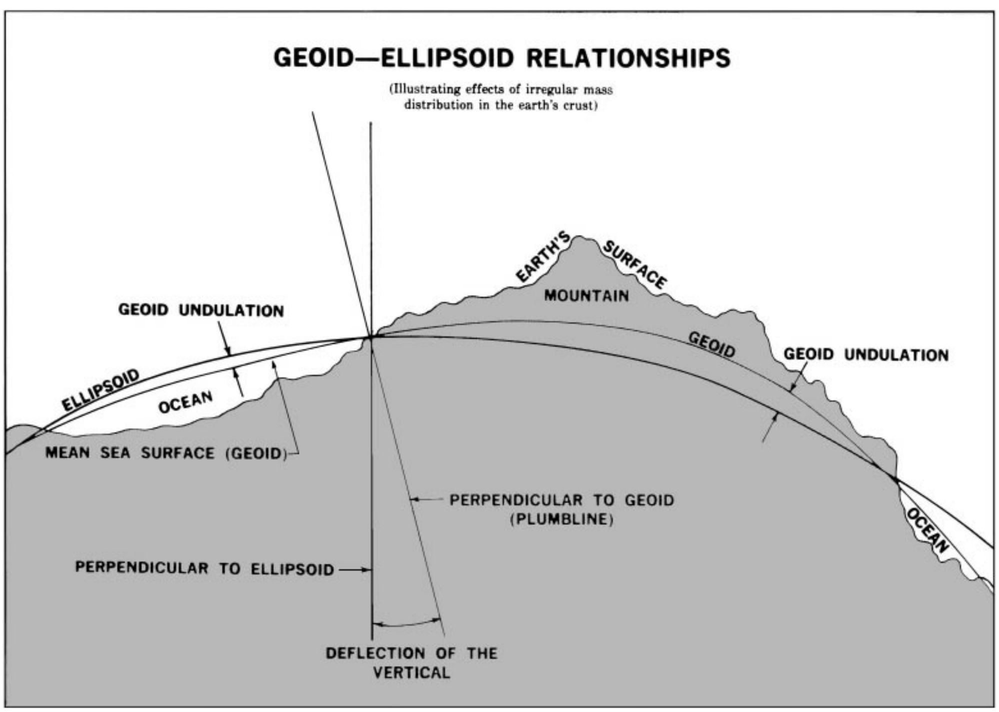


Figure 201. Geiod, ellipsoid, and topographic surface of the earth, and deflection of the vertical due to differences in mass.

The surface of the geoid, with some exceptions, tends to rise under mountains and to dip above ocean basins.

For geodetic, mapping, and charting purposes, it is necessary to use a regular or geometric shape which closely approximates the shape of the geoid either on a local or global scale and which has a specific mathematical expression. This shape is called the **ellipsoid**.

The separations of the geoid and ellipsoid are called **geoidal heights**, **geoidal undulations**, or **geoidal separations**.

The irregularities in density and depths of the material making up the upper crust of the earth also result in slight alterations of the direction of gravity. These alterations are reflected in the irregular shape of the geoid, the surface that is perpendicular to a plumb line.

Since the earth is in fact flattened slightly at the poles and bulges somewhat at the equator, the geometric figure used in geodesy to most nearly approximate the shape of the earth is the **oblate spheroid** or **ellipsoid of revolution**. This is the three dimensional shape obtained by rotating an ellipse about its minor axis.

202. Defining The Ellipsoid

An ellipsoid of revolution is uniquely defined by specifying two parameters. Geodesists, by convention, use the **semimajor axis** and **flattening**. The size is represented by the radius at the equator, the semimajor axis. The shape of the ellipsoid is given by the flattening, which indicates how closely an ellipsoid approaches a spherical shape. The flattening is the ratio of the difference between the semimajor and semiminor axes of the ellipsoid and the semimajor axis. See Figure 202. If a and b represent the semimajor and semiminor axes, respectively, of the ellipsoid, and f is the flattening,

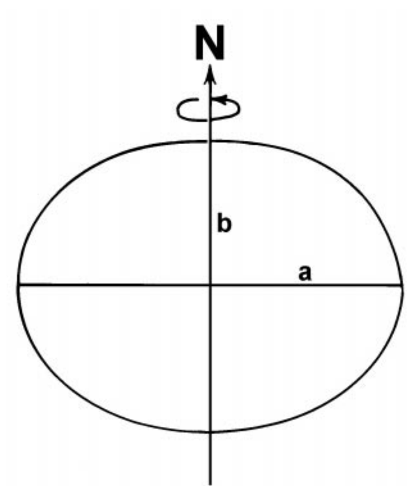


Figure 202. An ellipsoid of revolution, with semimajor axis (a), and semiminor axis (b).

$$f = \frac{a - b}{a} .$$

This ratio is about 1/300 for the earth.
The ellipsoidal earth model has its minor axis parallel to the earth's polar axis.

203. Ellipsoids And The Geoid As Reference Surfaces

Since the surface of the geoid is irregular and the surface of the ellipsoid is regular, no one ellipsoid can provide other than an approximation of part of the geoidal surface. Figure 203 illustrates an example. The ellipsoid that fits well in North America does not fit well in Europe; therefore, it must be positioned differently.

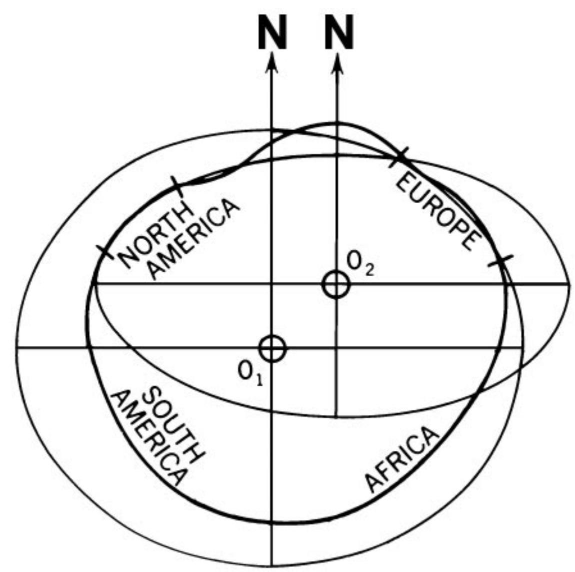


Figure 203. The geoid and two ellipsoids, illustrating how the ellipsoid which fits well in North America will not fit well in Europe, and must have a different origin. (exaggerated for clarity)

A number of reference ellipsoids are used in geodesy and mapping because an ellipsoid is mathematically simpler than the geoid.

204. Coordinates

The **astronomic latitude** is the angle between the plumb line at a station and the plane of the celestial equator. It is the latitude which results directly from observations of celestial bodies, uncorrected for deflection of the vertical component in the meridian (north-south) direction. Astronomic latitude applies only to positions on the earth. It is

reckoned from the astronomic equator (0°), north and south through 90°.

The **astronomic longitude** is the angle between the plane of the celestial meridian at a station and the plane of the celestial meridian at Greenwich. It is the longitude which results directly from observations of celestial bodies, uncorrected for deflection of the vertical component in the prime vertical (east-west) direction. These are the coordinates observed by the celestial navigator using a sextant and a very accurate clock based on the earth's rotation.

Astronomic observations by geodesists are made with optical instruments (theodolite, zenith camera, prismatic astrolabe) which all contain leveling devices. When properly adjusted, the vertical axis of the instrument coincides with the direction of gravity, and is, therefore, perpendicular to the geoid. Thus, astronomic positions are referenced to the geoid. Since the geoid is an irregular, non-mathematical surface, astronomic positions are wholly independent of each other.

The **geodetic latitude** is the angle which the normal to the ellipsoid at a station makes with the plane of the geodetic equator. In recording a geodetic position, it is essential that the geodetic datum on which it is based be also stated. A geodetic latitude differs from the corresponding astronomic latitude by the amount of the meridian component of the local deflection of the vertical.

The **geodetic longitude** is the angle between the plane of the geodetic meridian at a station and the plane of the geodetic meridian at Greenwich. A geodetic longitude differs from the corresponding astronomic longitude by the prime vertical component of the local deflection of the vertical divided by the cosine of the latitude. The geodetic coordinates are used for mapping.

The **geocentric latitude** is the angle at the center of the ellipsoid (used to represent the earth) between the plane of the equator, and a straight line (or radius vector) to a point on the surface of the ellipsoid. This differs from geodetic latitude because the earth is approximated more closely by a spheroid than a sphere and the meridians are ellipses, not perfect circles.

Both geocentric and geodetic latitudes refer to the reference ellipsoid and not the earth. Since the parallels of latitude are considered to be circles, geodetic longitude is geocentric, and a separate expression is not used.

Because of the oblate shape of the ellipsoid, the length of a degree of geodetic latitude is not everywhere the same, increasing from about 59.7 nautical miles at the equator to about 60.3 nautical miles at the poles.

A **horizontal geodetic datum** usually consists of the astronomic and geodetic latitude, and astronomic and geodetic longitude of an initial point (origin); an azimuth of a line (direction); the parameters (radius and flattening) of the ellipsoid selected for the computations; and the geoidal separation at the origin. A change in any of these quantities affects every point on the datum.

For this reason, while positions within a given datum are directly and accurately relateable, those from different datums must be transformed to a common datum for consistency.

TYPES OF GEODETIC SURVEY

205. Triangulation

The most common type of geodetic survey is known as **triangulation**. Triangulation consists of the measurement of the angles of a series of triangles. The principle of triangulation is based on plane trigonometry. If the distance along one side of the triangle and the angles at each end are accurately measured, the other two sides and the remaining angle can be computed. In practice, all of the angles of every triangle are measured to provide precise measurements. Also, the latitude and longitude of one end of the measured side along with the length and direction (azimuth) of the side provide sufficient data to compute the latitude and longitude of the other end of the side.

The measured side of the base triangle is called a **baseline**. Measurements are made as carefully and accurately as possible with specially calibrated tapes or wires of Invar, an alloy highly resistant to changes in length resulting from changes in temperature. The tape or wires are checked periodically against standard measures of length.

To establish an arc of triangulation between two widely separated locations, the baseline may be measured and longitude and latitude determined for the initial points at each location. The lines are then connected by a series of adjoining triangles forming quadrilaterals extending from each end. All angles of the triangles are measured repeatedly to reduce errors. With the longitude, latitude, and azimuth of the initial points, similar data is computed for each vertex of the triangles, thereby establishing triangulation stations, or geodetic control stations. The coordinates of each of the stations are defined as geodetic coordinates.

Triangulation is extended over large areas by connecting and extending series of arcs to form a network or triangulation system. The network is adjusted in a manner which reduces the effect of observational errors to a minimum. A denser distribution of geodetic control is achieved in a system by subdividing or filling in with other surveys.

There are four general classes or orders of triangulation. **First-order** (primary) triangulation is the most precise and exact type. The most accurate instruments and rigorous computation methods are used. It is costly and time-consuming, and is usually used to provide the basic framework of control data for an area, and the determination of the figure of the earth. The most accurate first-order surveys furnish control points which can be interrelated with an accuracy ranging from 1 part in 25,000 over short distances to

approximately 1 part in 100,000 for long distances.

Second-order triangulation furnishes points closer together than in the primary network. While second-order surveys may cover quite extensive areas, they are usually tied to a primary system where possible. The procedures are less exacting and the proportional error is 1 part in 10,000.

Third-order triangulation is run between points in a secondary survey. It is used to densify local control nets and position the topographic and hydrographic detail of the area. Triangle error can amount to 1 part in 5,000.

The sole accuracy requirement for **fourth-order** triangulation is that the positions be located without any appreciable error on maps compiled on the basis of the control. Fourth-order control is done primarily as mapping control.

206. Trilateration, Traverse, And Vertical Surveying

Trilateration involves measuring the sides of a chain of triangles or other polygons. From them, the distance and direction from A to B can be computed. Figure 206 shows this process.

Traverse involves measuring distances and the angles between them without triangles for the purpose of computing the distance and direction from A to B. See Figure 206.

Vertical surveying is the process of determining elevations above mean sea-level. In geodetic surveys executed primarily for mapping, geodetic positions are referred to an ellipsoid, and the elevations of the positions are referred to the geoid. However, for satellite geodesy the geoidal heights must be considered to establish the correct height above the geoid.

Precise geodetic **leveling** is used to establish a basic network of vertical control points. From these, the height of other positions in the survey can be determined by supplementary methods. The mean sea-level surface used as a reference (vertical datum) is determined by averaging the hourly water heights for a specified period of time at specified tide gauges.

There are three leveling techniques: **differential**, **trigonometric**, and **barometric**. Differential leveling is the most accurate of the three methods. With the instrument locked in position, readings are made on two calibrated staffs held in an upright position ahead of and behind the instrument. The difference between readings is the difference in elevation between the points.

Trigonometric leveling involves measuring a vertical angle from a known distance with a theodolite and computing the elevation of the point. With this method, vertical measurement can be made at the same time horizontal angles are measured for triangulation. It is, therefore, a somewhat more economical method but less accurate than differential leveling. It is often the only practical method of establishing accurate elevation control in mountainous areas.

In barometric leveling, differences in height are determined by measuring the differences in atmospheric pressure at various elevations. Air pressure is measured by mercurial or aneroid barometer, or a boiling point thermometer. Although the accuracy of this method is not as great as either of the other two, it obtains relative heights very rapidly at points which are fairly far apart. It is used in reconnaissance and exploratory surveys where more accurate measurements will be made later or where a high degree of accuracy is not required.

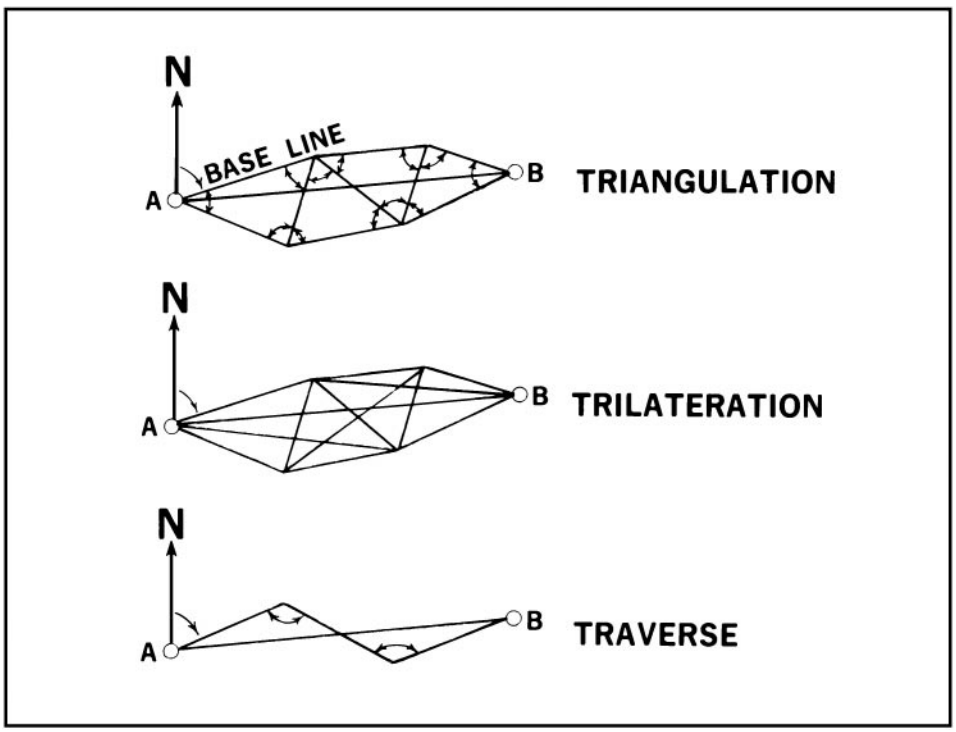


Figure 206. Triangulation, trilateration, and traverse.

DATUM CONNECTIONS

207. Definitions

A **datum** is defined as any numerical or geometrical quantity or set of such quantities which serves as a reference point to measure other quantities.

In geodesy, as well as in cartography and navigation, two types of datums must be considered: a **horizontal datum** and a **vertical datum**. The horizontal datum forms the basis for computations of horizontal position. The vertical datum provides the reference to measure heights. A horizontal datum may be defined at an origin point on the ellipsoid (local datum) such that the center of the ellipsoid coincides with the Earth's center of mass (geocentric datum). The coordinates for points in specific geodetic surveys and triangulation networks are computed from certain initial quantities, or datums.

208. Preferred Datums

In areas of overlapping geodetic triangulation networks, each computed on a different datum, the coordinates of the points given with respect to one datum will differ from those given with respect to the other. The differences can be used to derive transformation formulas. Datums are connected by developing transformation formulas at common points, either between overlapping control networks or by satellite connections.

Many countries have developed national datums which differ from those of their neighbors. Accordingly, national maps and charts often do not agree along national borders.

The **North American Datum, 1927** (NAD 27) has been used in the United States for about 50 years, but it is being replaced by datums based on the **World Geodetic System**. NAD 27 coordinates are based on the latitude and longitude of a triangulation station (the reference point) at Mead's Ranch in Kansas, the azimuth to a nearby triangulation station called Waldo, and the mathematical parameters of the Clarke Ellipsoid of 1866. Other datums throughout the world use different assumptions as to origin points and ellipsoids.

The origin of the **European Datum** is at Potsdam,

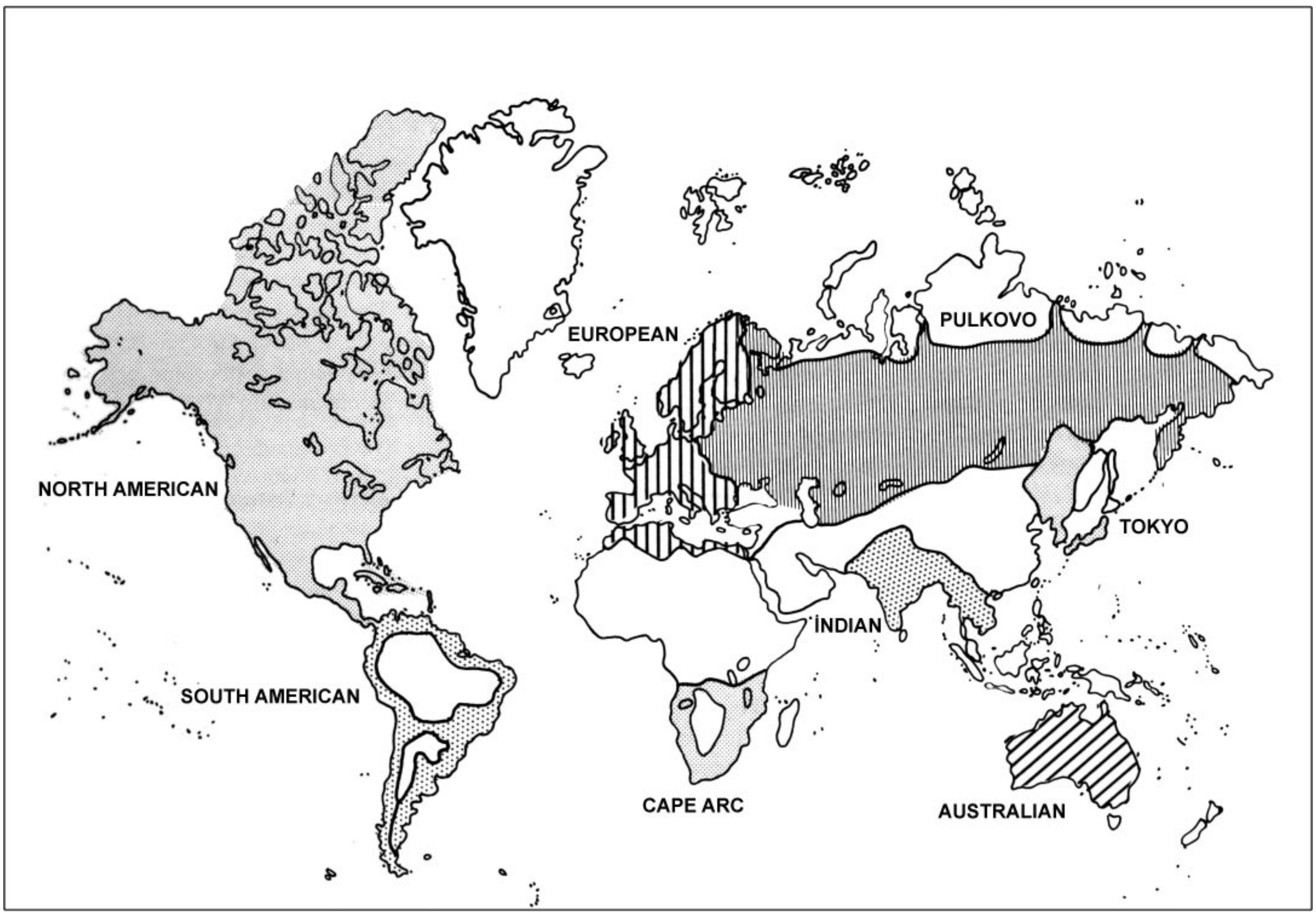


Figure 208. Major geodetic datum blocks.

Germany. Numerous national systems have been joined into a large datum based upon the International Ellipsoid of 1924 which was oriented by a modified astrogeodetic method. European, African, and Asian triangulation chains were connected, and African measurements from Cairo to Cape Town were completed. Thus, all of Europe, Africa, and Asia are molded into one great system. Through common survey stations, it was also possible to convert data from the Russian Pulkova, 1932 system to the European Datum, and as a result, the European Datum includes triangulation as far east as the 84th meridian. Additional ties across the Middle East have permitted connection of the Indian and European Datums.

The **Ordnance Survey of Great Britain 1936 Datum** has no point of origin. The data was derived as a best fit between retriangulation and original values of 11 points of the earlier Principal Triangulation of Great Britain (1783-1853).

Tokyo Datum has its origin in Tokyo. It is defined in terms of the Bessel Ellipsoid and oriented by a single astronomic station. Triangulation ties through Korea connect the Japanese datum with the Manchurian datum. Unfortunately, Tokyo is situated on a steep slope on the geoid, and the single-station orientation has resulted in large systematic geoidal separations as the system is extended from its initial point.

The **Indian Datum** is the preferred datum for India and several adjacent countries in Southeast Asia. It is computed on the Everest Ellipsoid with its origin at Kalianpur, in central India. It is largely the result of the untiring work of Sir George Everest (1790-1866), Surveyor General in India from 1830 to 1843. He is best known by the mountain named after him, but by far his most important legacy was the survey of the Indian subcontinent.

MODERN GEODETIC SYSTEMS

209. Development Of The World Geodetic System

By the late 1950's the increasing range and sophistication of weapons systems had rendered local or national datums inadequate for military purposes; these new weapons required datums at least continental in scope. In response to these requirements, the U.S. Department of Defense generated a geocentric reference system to which different geodetic networks could be referred and established compatibility between the coordinates of sites of interest. Efforts of the Army, Navy, and Air Force were combined leading to the development of the DoD **World Geodetic System of 1960 (WGS 60)**.

In January 1966, a World Geodetic System Committee was charged with the responsibility for developing an improved WGS needed to satisfy mapping, charting, and geodetic requirements. Additional surface gravity observations, results from the extension of triangulation and trilateration networks, and large amounts of Doppler and optical satellite data had become available since the development of WGS 60. Using the additional data and improved techniques, the Committee produced **WGS 66** which served DoD needs following its implementation in 1967.

The same World Geodetic System Committee began work in 1970 to develop a replacement for WGS 66. Since the development of WGS 66, large quantities of additional data had become available from both Doppler and optical satellites, surface gravity surveys, triangulation and trilateration surveys, high precision traverses, and astronomic surveys.

In addition, improved capabilities had been developed in both computers and computer software. Continued research in computational procedures and error analyses had produced better methods and an improved facility for handling and combining data. After an extensive effort extending over a period of approximately three years, the Committee completed the development of the Department of Defense **World Geodetic System 1972 (WGS 72)**.

Further refinement of WGS 72 resulted in the new **World Geodetic System of 1984 (WGS 84)**. As of 1990, WGS 84 is being used for chart making by DMA. For surface navigation, WGS 60, 66, 72 and the new WGS 84 are essentially the same, so that positions computed on any WGS coordinates can be plotted directly on the others without correction.

The WGS system is not based on a single point, but many points, fixed with extreme precision by satellite fixes and statistical methods. The result is an ellipsoid which fits the real surface of the earth, or geoid, far more accurately than any other. The WGS system is applicable worldwide. All regional datums can be referenced to WGS once a survey tie has been made.

210. The New North American Datum Of 1983

The Coast And Geodetic Survey of the National Ocean Service (NOS), NOAA, is responsible for charting United States waters. From 1927 to 1987, U.S. charts were based on NAD 27, using the Clarke 1866 ellipsoid. In 1989, the U.S. officially switched to **NAD 83** (navigationally equivalent to WGS 84 and other WGS systems) for all mapping and charting purposes, and all new NOS chart production is based on this new standard.

The grid of interconnected surveys which criss-crosses the United States consists of some 250,000 control points, each consisting of the latitude and longitude of the point, plus additional data such as elevation. Converting the NAD 27 coordinates to NAD 83 involved recomputing the position of each point based on the new NAD 83 datum. In addition to the 250,000 U.S. control points, several thousand more were added to tie in surveys from Canada, Mexico, and Central America.

Conversion of new edition charts to the new datums, either WGS 84 or NAD 83, involves converting reference

points on each chart from the old datum to the new, and adjusting the latitude and longitude grid (known as the graticule) so that it reflects the newly plotted positions. This adjustment of the graticule is the only difference between charts which differ only in datum. All charted features remain in exactly the same relative positions.

IMPACTS ON NAVIGATION

211. Datum Shifts

One impact of different datums on navigation appears when a navigation system provides a fix based on a datum different from that used for the nautical chart. The resulting plotted position may be different from the actual location on that chart. This difference is known as a **datum shift**.

Another effect on navigation occurs when shifting between charts that have been made using different datums. If any position is replotted on a chart of another datum using only latitude and longitude for locating that position, the newly plotted position will not match with respect to other charted features. This datum shift may be avoided by replotting using bearings and ranges to common points. If datum shift conversion notes for the applicable datums are given on the charts, positions defined by latitude and longitude may be replotted after applying the noted correction.

The positions given for chart corrections in the Notice to Mariners reflect the proper datum for each specific chart and edition number. Due to conversion of charts based on old datums to more modern ones, and the use of many different datums throughout the world, chart corrections intended for one edition of a chart may not be safely plotted on any other.

These datum shifts are not constant throughout a given area, but vary according to how the differing datums fit together. For example, the NAD 27 to NAD 83 conversion results in changes in latitude of 40 meters in Miami, 11 meters in New York, and 20 meters in Seattle. Longitude changes for this conversion are about 22 meters in Miami, 35 meters in New York, and 93 meters in Seattle.

Most charts produced by DMA and NOS show a "datum note." This note is usually found in the title block or in the upper left margin of the chart. According to the year of the chart edition, the scale, and policy at the time of production, the note may say "World Geodetic System 1972 (WGS-72)", "World Geodetic System 1984 (WGS-84)", or "World Geodetic System (WGS)." A datum note for a chart for which satellite positions can be plotted without correction will read: "Positions obtained from satellite navigation systems referred to (REFERENCE DATUM) can be plotted directly on this chart."

DMA reproductions of foreign chart's will usually be in the datum or reference system of the producing country. In these cases a conversion factor is given in the following format: "Positions obtained from satellite navigation systems referred to the (Reference Datum) must be moved X.XX minutes (Northward/Southward) and X.XX minutes (Eastward/ Westward) to agree with this chart."

Some charts cannot be tied in to WGS because of lack of recent surveys. Currently issued charts of some areas are based on surveys or use data obtained in the age of sailing ships. The lack of surveyed control points means that they cannot be properly referenced to modern geodetic systems. In this case there may be a note that says: "Adjustments to WGS cannot be determined for this chart."

A few charts may have no datum note at all, but may carry a note which says: "From various sources to (year)." In these cases there is no way for the navigator to determine the mathematical difference between the local datum and WGS positions. However, if a radar or visual fix can be very accurately determined, the difference between this fix and a satellite fix can determine an approximate correction factor which will be reasonably consistent for that local area.

212. Minimizing Errors Caused By Differing Datums

To minimize problems caused by differing datums:

- Plot chart corrections only on the specific charts and editions for which they are intended. Each chart correction is specific to only one edition of a chart. When the same correction is made on two charts based on different datums, the positions for the same feature may differ slightly. This difference is equal to the datum shift between the two datums for that area.
- Try to determine the source and datum of positions of temporary features, such as drill rigs. In general they are given in the datum used in the area in question. Since these are usually positioned using satellites, WGS is the normal datum. A datum correction, if needed, might be found on a chart of the area.
- Remember that if the datum of a plotted feature is not known, position inaccuracies may result. It is wise to allow a margin of error if there is any doubt about the datum.
- Know how the datum of the positioning system you are using (Loran, GPS, etc.) relates to your chart. GPS and other modern positioning systems use the WGS datum. If your chart is on any other datum, you must apply a datum correction when plotting the GPS position of the chart.

Modern geodesy can support the goal of producing all the world's charts on the same datum. Coupling an electronic chart with satellite positioning will eliminate the problem of differing datums because electronically derived positions and the video charts on which they are displayed are derived from one of the new worldwide datums.

CHAPTER 3

NAUTICAL CHARTS

CHART FUNDAMENTALS

300. Definitions

A **nautical chart** represents part of the spherical earth on a plane surface. It shows water depth, the shoreline of adjacent land, topographic features, aids to navigation, and other navigational information. It is a work area on which the navigator plots courses, ascertains positions, and views the relationship of the ship to the surrounding area. It assists the navigator in avoiding dangers and arriving safely at his destination.

The actual form of a chart may vary. Traditional nautical charts have been printed on paper. **Electronic charts** consisting of a digital data base and a display system are in use and will eventually replace paper charts for operational use. An electronic chart is not simply a digital version of a paper chart; it introduces a new navigation methodology with capabilities and limitations very different from paper charts. The electronic chart will eventually become the legal equivalent of the paper chart when approved by the International Maritime Organization and the various governmental agencies which regulate navigation. Currently, however, mariners must maintain a paper chart on the bridge. See Chapter 14, The Integrated Bridge, for a discussion of electronic charts.

Should a marine accident occur, the nautical chart in use at the time takes on legal significance. In cases of grounding, collision, and other accidents, charts become critical records for reconstructing the event and assigning liability. Charts used in reconstructing the incident can also have tremendous training value.

301. Projections

Because a cartographer cannot transfer a sphere to a flat surface without distortion, he must project the surface of a sphere onto a **developable surface**. A developable surface is one that can be flattened to form a plane. This process is known as **chart projection**. If points on the surface of the sphere are projected from a single point, the projection is said to be **perspective** or **geometric**.

As the use of electronic charts becomes increasingly widespread, it is important to remember that the same cartographic principles that apply to paper charts apply to their depiction on video screens.

302. Selecting A Projection

Each projection has certain preferable features. However, as the area covered by the chart becomes smaller, the differences between various projections become less noticeable. On the largest scale chart, such as of a harbor, all projections are practically identical. Some desirable properties of a projection are:

1. True shape of physical features.
2. Correct angular relationship. A projection with this characteristic is **conformal** or **orthomorphic**.
3. Equal area, or the representation of areas in their correct relative proportions.
4. Constant scale values for measuring distances.
5. Great circles represented as straight lines.
6. Rhumb lines represented as straight lines.

Some of these properties are mutually exclusive. For example, a single projection cannot be both conformal and equal area. Similarly, both great circles and rhumb lines cannot be represented on a single projection as straight lines.

303. Types Of Projections

The type of developable surface to which the spherical surface is transferred determines the projection's classification. Further classification depends on whether the projection is centered on the equator (equatorial), a pole (polar), or some point or line between (oblique). The name of a projection indicates its type and its principal features.

Mariners most frequently use a **Mercator projection**, classified as a **cylindrical projection** upon a plane, the cylinder tangent along the equator. Similarly, a projection based upon a cylinder tangent along a meridian is called **transverse** (or inverse) **Mercator** or **transverse** (or inverse) **orthomorphic**. The Mercator is the most common projection used in maritime navigation, primarily because rhumb lines plot as straight lines.

In a **simple conic projection**, points on the surface of the earth are transferred to a tangent cone. In the **Lambert conformal projection**, the cone intersects the earth (a secant cone) at two small circles. In a **polyconic projection**, a series of tangent cones is used.

In an **azimuthal** or **zenithal projection**, points on the earth are transferred directly to a plane. If the origin of the projecting rays is the center of the earth, a **gnomonic projection** results; if it is the point opposite the plane's point of tangency, a **stereographic projection**; and if at infinity (the projecting lines being parallel to each other), an **orthographic projection**. The gnomonic, stereographic, and orthographic are **perspective projections**. In an **azimuthal equidistant projection**, which is not perspective, the scale of distances is constant along any radial line from the point of tangency. See Figure 303.

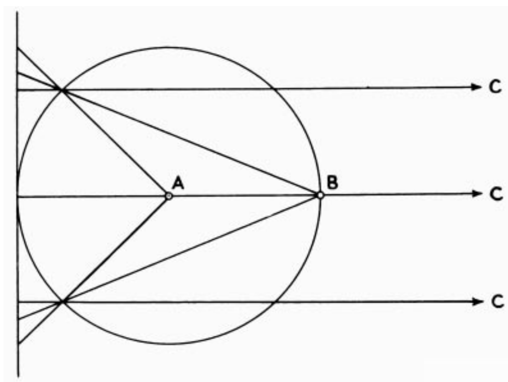


Figure 303. Azimuthal projections: A, gnomonic; B, stereographic; C, (at infinity) orthographic.

Cylindrical and **plane projections** are special conical projections, using heights infinity and zero, respectively.

A **graticule** is the network of latitude and longitude lines laid out in accordance with the principles of any projection.

304. Cylindrical Projections

If a cylinder is placed around the earth, tangent along the equator, and the planes of the meridians are extended, they intersect the cylinder in a number of vertical lines. See Figure 304. These parallel lines of projection are equidistant from each other, unlike the terrestrial meridians from which they are derived which converge as the latitude increases. On the earth, parallels of latitude are perpendicular to the meridians, forming circles of progressively smaller diameter as the latitude increases. On the cylinder they are shown perpendicular to the projected meridians, but because a cylinder is everywhere of the same diameter, the projected parallels are all the same size.

If the cylinder is cut along a vertical line (a meridian) and spread out flat, the meridians appear as equally spaced vertical lines; and the parallels appear as horizontal lines. The parallels' relative spacing differs in the various types of cylindrical projections.

If the cylinder is tangent along some great circle other than the equator, the projected pattern of latitude and longitude lines appears quite different from that described above, since the line of tangency and the equator no longer coincide. These projections are classified as **oblique** or **transverse projections**.

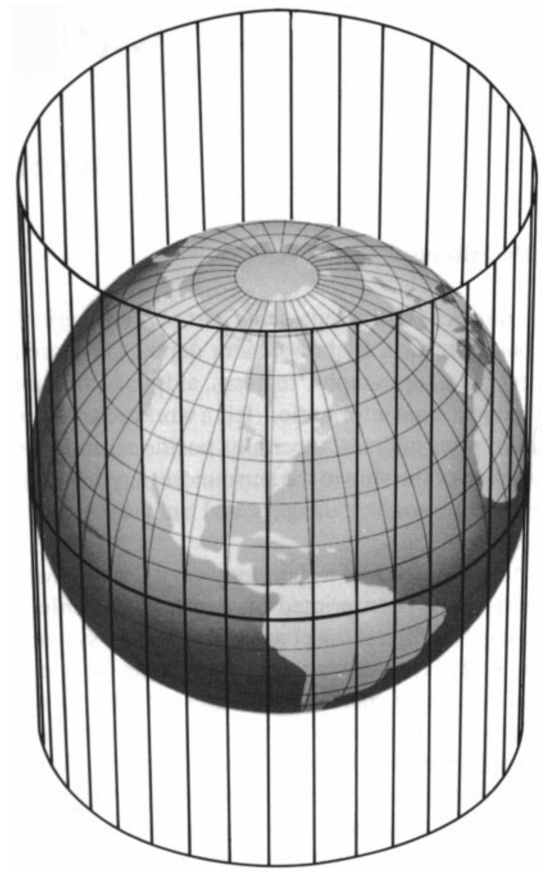


Figure 304. A cylindrical projection.

305. Mercator Projection

Navigators most often use the plane conformal projection known as the **Mercator projection**. The Mercator projection is not perspective, and its parallels can be derived mathematically as well as projected geometrically. Its distinguishing feature is that both the meridians and parallels are expanded at the same ratio with increased latitude. The expansion is equal to the secant of the latitude, with a small correction for the ellipticity of the earth. Since the secant of 90° is infinity, the projection cannot include the poles. Since the projection is conformal, expansion is the same in all directions and angles are correctly shown. Rhumb lines appear as straight lines, the directions of which can be measured directly on the chart. Distances can also be measured directly if the spread of latitude is small. Great circles, except meridians and the equator, appear as curved lines concave to the equator. Small areas appear in their correct shape but of increased size unless they are near the equator.

306. Meridional Parts

At the equator a degree of longitude is approximately

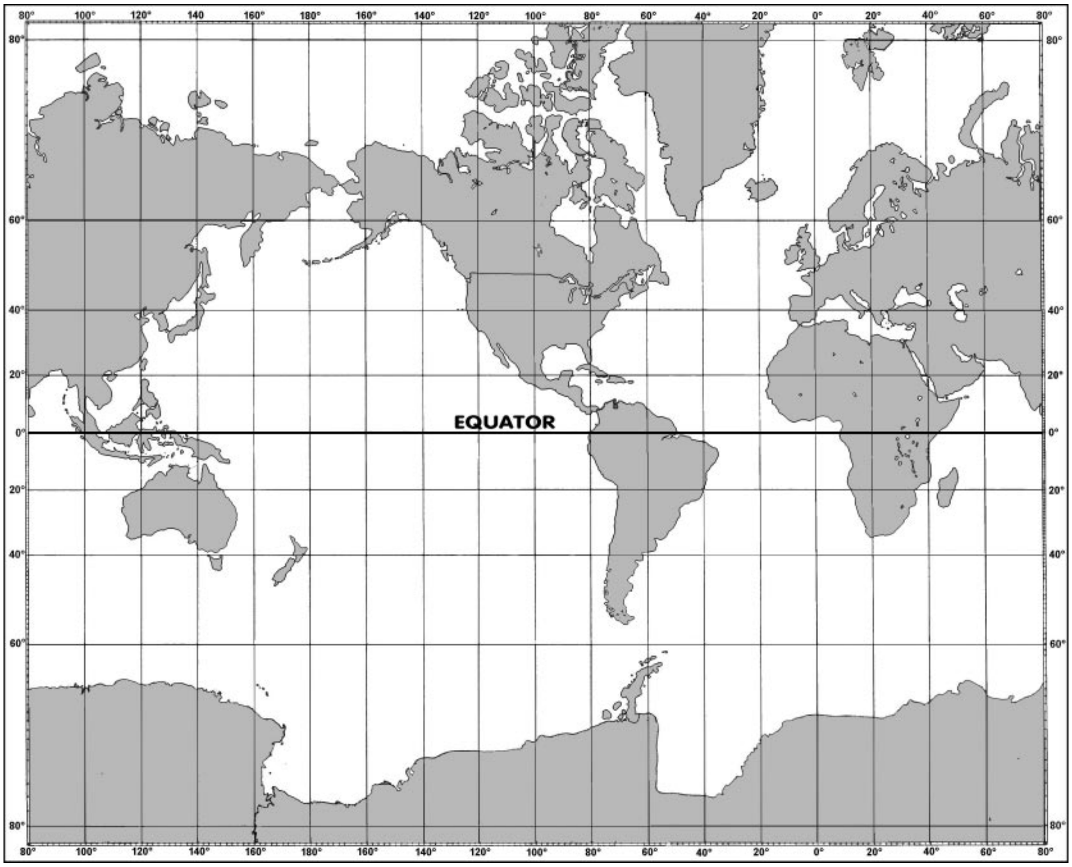


Figure 306. A Mercator map of the world.

equal in length to a degree of latitude. As the distance from the equator increases, degrees of latitude remain approximately the same, while degrees of longitude become progressively shorter. Since degrees of longitude appear everywhere the same length in the Mercator projection, it is necessary to increase the length of the meridians if the expansion is to be equal in all directions. Thus, to maintain the correct proportions between degrees of latitude and degrees of longitude, the degrees of latitude must be progressively longer as the distance from the equator increases. This is illustrated in Figure 306.

The length of a meridian, increased between the equator and any given latitude, expressed in minutes of arc at the equator as a unit, constitutes the number of meridional parts (M) corresponding to that latitude. Meridional parts, given in Table 6 for every minute of latitude from the equator to the pole, make it possible to construct a Mercator chart and to solve problems in Mercator sailing. These values are for the WGS ellipsoid of 1984.

307. Transverse Mercator Projections

Constructing a chart using Mercator principles, but with the cylinder tangent along a meridian, results in a **transverse Mercator** or **transverse orthomorphic projection**. The word "inverse" is used interchangeably with "transverse." These projections use a fictitious graticule similar to, but offset from, the familiar network of meridians and parallels. The tangent great circle is the fictitious equator. Ninety degrees from it are two fictitious poles. A group of great circles through these poles and perpendicular to the tangent great circle are the fictitious meridians, while a series of circles parallel to the plane of the tangent great circle form the fictitious parallels. The actual meridians and parallels appear as curved lines.

A straight line on the transverse or oblique Mercator projection makes the same angle with all fictitious meridians, but not with the terrestrial meridians. It is therefore a fictitious rhumb line. Near the tangent great circle, a straight line closely approximates a great circle. The projection is most useful in this area. Since the area of minimum distortion is near a meridian, this projection is useful for charts covering a large band of latitude and extending a relatively short distance on each side of the tangent meridian. It is sometimes used for star charts showing the evening sky at various seasons of the year. See Figure 307.

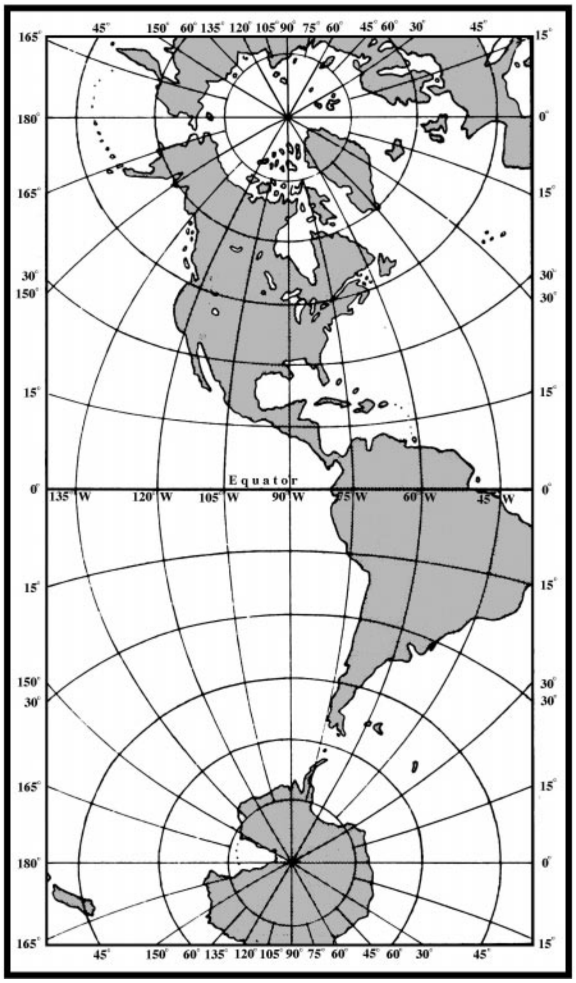


Figure 307. A transverse Mercator map of the Western Hemisphere.

308. Universal Transverse Mercator (UTM) Grid

The **Universal Transverse Mercator (UTM)** grid is a military grid superimposed upon a transverse Mercator graticule, or the representation of these grid lines upon any graticule. This grid system and these projections are often used for large-scale (harbor) nautical charts and military charts.

309. Oblique Mercator Projections

A Mercator projection in which the cylinder is tangent along a great circle other than the equator or a meridian is called an **oblique Mercator** or **oblique orthomorphic projection**. This projection is used principally to depict an area in the near vicinity of an oblique great circle. Figure 309c, for example, shows the great circle joining Washington and Moscow. Figure 309d shows an oblique Mercator map with the great circle between these two centers as the tangent great circle or fictitious equator. The limits of the chart of Figure 309c are indicated in Figure 309d. Note the large variation in scale as the latitude changes.

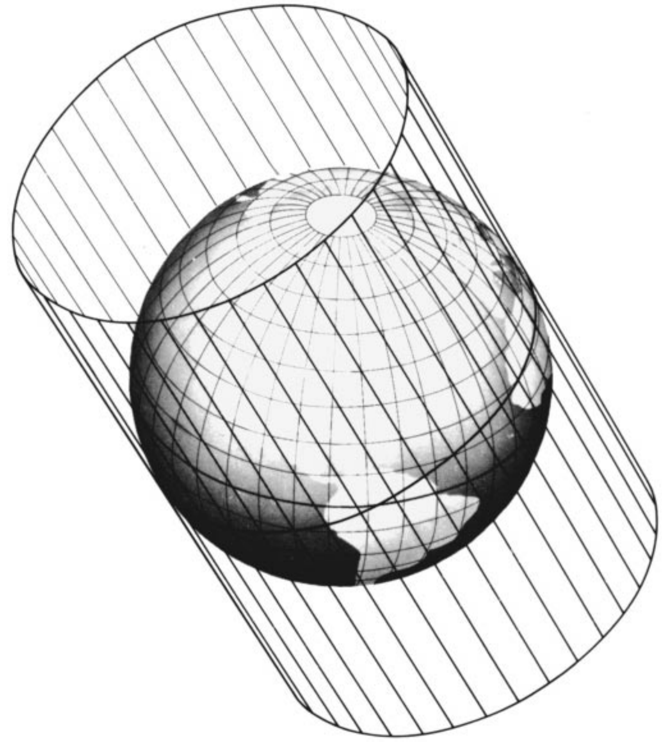


Figure 309a. An oblique Mercator projection.

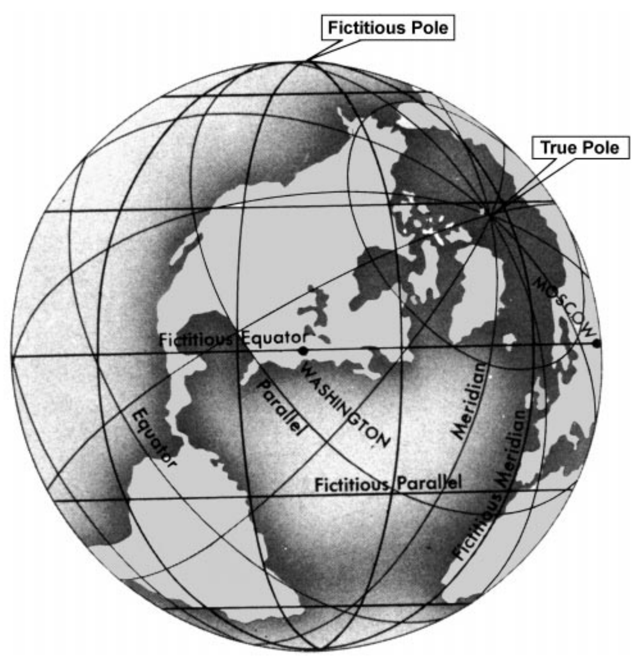


Figure 309b. The fictitious graticle of an oblique Mercator projection.

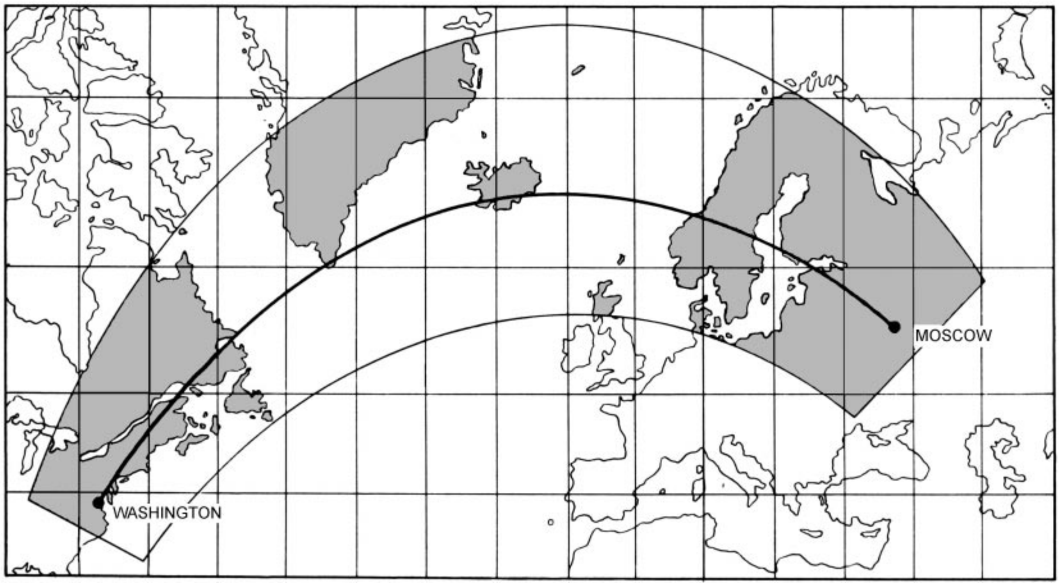


Figure 309c. The great circle between Washington and Moscow as it appears on a Mercator map.

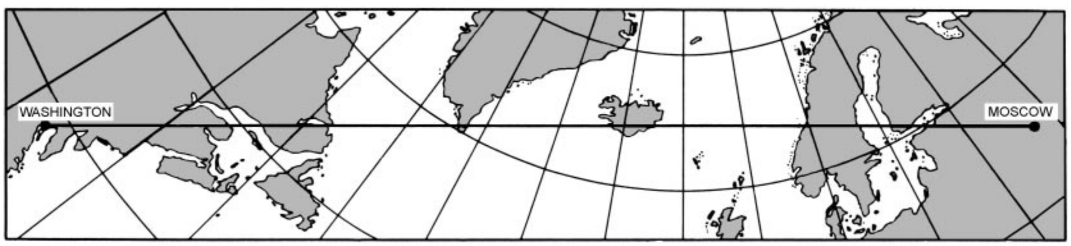


Figure 309d. An oblique Mercator map based upon a cylinder tangent along the great circle through Washington and Moscow. The map includes an area 500 miles on each side of the great circle. The limits of this map are indicated on the Mercator map of Figure 309c.

310. Rectangular Projection

A cylindrical projection similar to the Mercator, but with uniform spacing of the parallels, is called a **rectangular projection**. It is convenient for graphically depicting information where distortion is not important. The principal navigational use of this projection is for the star chart of the Air Almanac, where positions of stars are plotted by rectangular coordinates representing declination (ordinate) and sidereal hour angle (abscissa). Since the meridians are parallel, the parallels of latitude (including the equator and the poles) are all represented by lines of equal length.

311. Conic Projections

A **conic projection** is produced by transferring points from the surface of the earth to a cone or series of cones. This cone is then cut along an element and spread out flat to form the chart. When the axis of the cone coincides with the axis of the earth, then the parallels appear as arcs of circles, and the meridians appear as either straight or curved lines converging toward the nearer pole. Limiting the area covered to that part of the cone near the surface of the earth limits distortion. A parallel along which there is no distortion is called a **standard parallel**. Neither the transverse conic projection, in which the axis of the cone is in the equatorial plane, nor the oblique conic projection, in which the axis of the cone is oblique to the plane of the equator, is ordinarily used for navigation. They are typically used for illustrative maps.

Using cones tangent at various parallels, a secant (intersecting) cone, or a series of cones varies the appearance and features of a conic projection.

312. Simple Conic Projection

A conic projection using a single tangent cone is a **simple conic projection** (Figure 312a). The height of the cone increases as the latitude of the tangent parallel decreases. At the equator, the height reaches infinity and the cone be-

comes a cylinder. At the pole, its height is zero, and the cone becomes a plane. Similar to the Mercator projection, the simple conic projection is not perspective since only the meridians are projected geometrically, each becoming an element of the cone. When this projection is spread out flat to form a map, the meridians appear as straight lines converging at the apex of the cone. The standard parallel, where the cone is tangent to the earth, appears as the arc of a circle with its center at the apex of the cone. The other

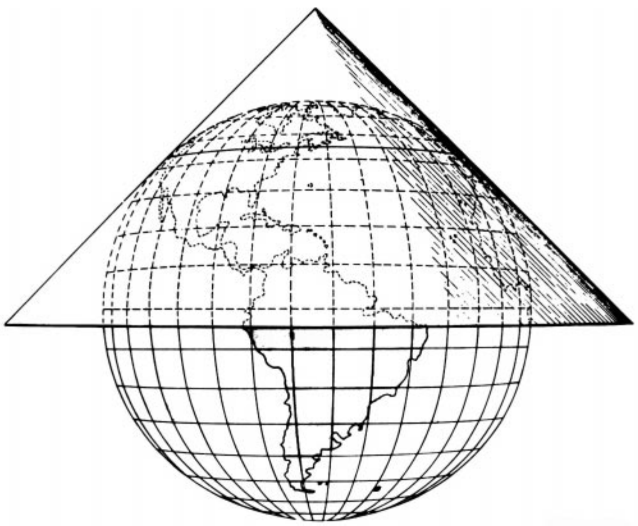


Figure 312a. A simple conic projection.

parallels are concentric circles. The distance along any meridian between consecutive parallels is in correct relation to the distance on the earth, and, therefore, can be derived mathematically. The pole is represented by a circle (Figure 312b). The scale is correct along any meridian and along the standard parallel. All other parallels are too great in length, with the error increasing with increased distance from the standard parallel. Since the scale is not the same in all directions about every point, the projection is neither a conformal nor equal-area projection. Its non-conformal nature is its principal disadvantage for navigation.

Since the scale is correct along the standard parallel and varies uniformly on each side, with comparatively little distortion near the standard parallel, this projection is useful for mapping an area covering a large spread of longitude and a comparatively narrow band of latitude. It was developed by Claudius Ptolemy in the second century A.D. to map just such an area: the Mediterranean Sea.

313. Lambert Conformal Projection

The useful latitude range of the simple conic projection can be increased by using a secant cone intersecting the earth at two standard parallels. See Figure 313. The area between the two standard parallels is compressed, and that beyond is expanded. Such a projection is called either a **secant conic** or **conic projection with two standard parallels**.

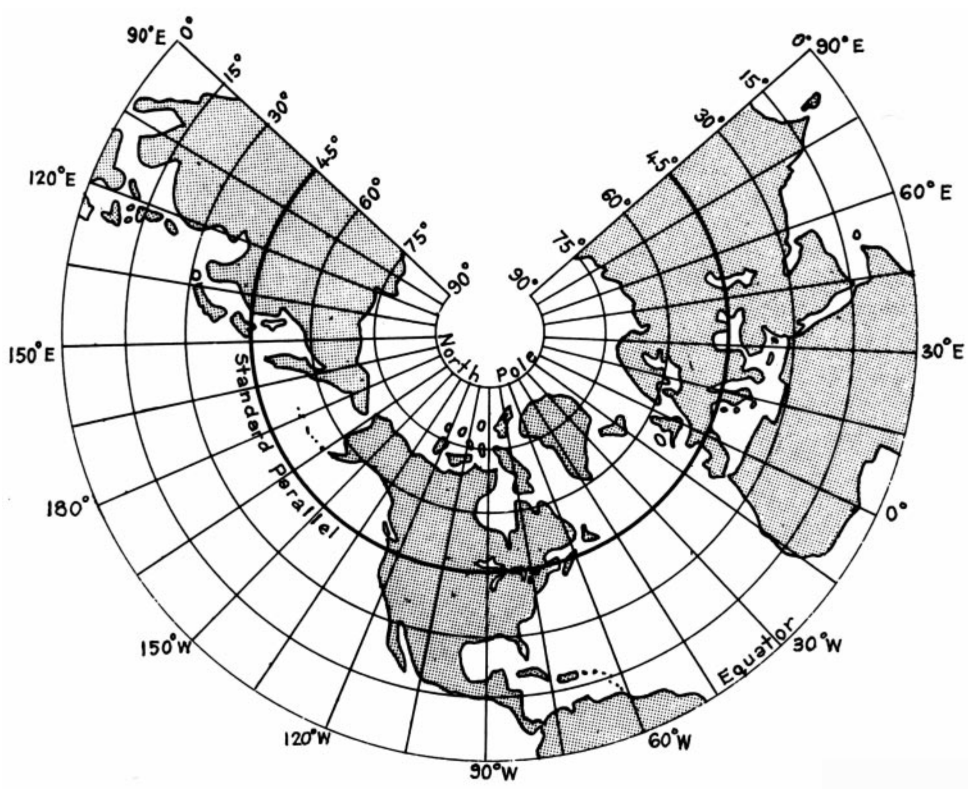


Figure 312b. A simple conic map of the Northern Hemisphere.

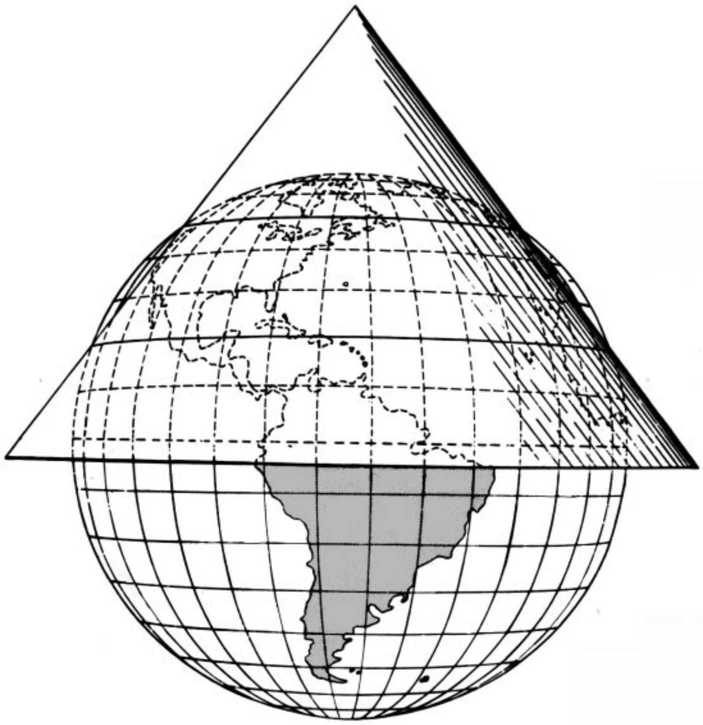


Figure 313. A secant cone for a conic projection with two standard parallels.

If in such a projection the spacing of the parallels is altered, such that the distortion is the same along them as along the meridians, the projection becomes conformal. This modification produces the **Lambert conformal projection**. If the chart is not carried far beyond the standard parallels, and if these are not a great distance apart, the distortion over the entire chart is small.

A straight line on this projection so nearly approximates a great circle that the two are nearly identical. Radio beacon signals travel great circles; thus, they can be plotted on this projection without correction. This feature, gained without sacrificing conformality, has made this projection popular for aeronautical charts because aircraft make wide use of radio aids to navigation. Except in high latitudes, where a slightly modified form of this projection has been used for polar charts, it has not replaced the Mercator projection for marine navigation.

314. Polyconic Projection

The latitude limitations of the secant conic projection can be minimized by using a series of cones. This results in a **polyconic projection**. In this projection, each parallel is the base of a tangent cone . At the edges of the chart, the area between parallels is expanded to eliminate gaps. The scale is correct along any parallel and along the central meridian of the projection. Along other meridians the scale increases with increased difference of longitude from the central meridian. Parallels appear as nonconcentric circles; meridians appear as curved lines converging toward the pole and concave to the central meridian.

The polyconic projection is widely used in atlases, particularly for areas of large range in latitude and reasonably large range in longitude, such as continents. However, since it is not conformal, this projection is not customarily used in navigation.

315. Azimuthal Projections

If points on the earth are projected directly to a plane surface, a map is formed at once, without cutting and flattening, or "developing." This can be considered a special case of a conic projection in which the cone has zero height.

The simplest case of the **azimuthal projection** is one in which the plane is tangent at one of the poles. The meridians are straight lines intersecting at the pole, and the parallels are concentric circles with their common center at the pole. Their spacing depends upon the method used to transfer points from the earth to the plane.

If the plane is tangent at some point other than a pole, straight lines through the point of tangency are great circles, and concentric circles with their common center at the point of tangency connect points of equal distance from that point. Distortion, which is zero at the point of tangency, increases along any great circle through this point. Along any circle whose center is the point of tangency, the distortion is constant. The bearing of any point from the point of tangency is correctly represented. It is for this reason that these projections are called **azimuthal**. They are also called **zenithal**. Several of the common azimuthal projections are perspective.

316. Gnomonic Projection

If a plane is tangent to the earth, and points are projected geometrically from the center of the earth, the result is a **gnomonic projection**. See Figure 316a. Since the projection is perspective, it can be demonstrated by placing a light at the center of a transparent terrestrial globe and holding a

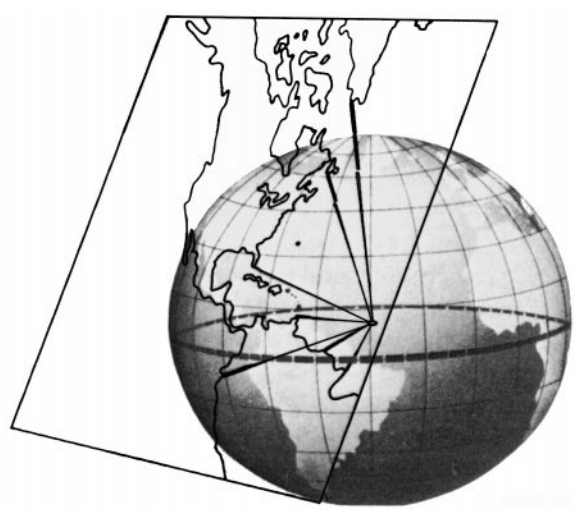


Figure 316a. An oblique gnomonic projection.

flat surface tangent to the sphere.

In an **oblique gnomonic projection** the meridians appear as straight lines converging toward the nearer pole. The parallels, except the equator, appear as curves (Figure 316b). As in all azimuthal projections, bearings from the point of tangency are correctly represented. The distance scale, however, changes rapidly. The projection is neither conformal nor equal area. Distortion is so great that shapes, as well as distances and areas, are very poorly represented, except near the point of tangency.

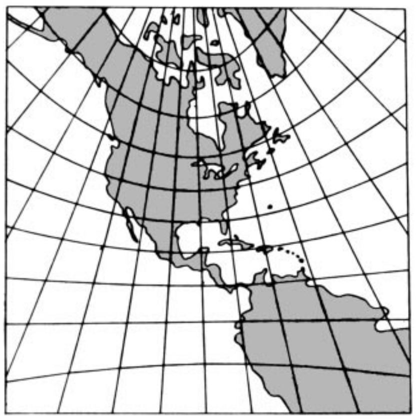


Figure 316b. An oblique gnomonic map with point of tangency at latitude 30°N, longitude 90°W.

The usefulness of this projection rests upon the fact that any great circle appears on the map as a straight line, giving charts made on this projection the common name **great-circle charts**.

Gnomonic charts are most often used for planning the great-circle track between points. Points along the determined track are then transferred to a Mercator projection. The great circle is then followed by following the rhumb lines from one point to the next. Computer programs which automatically calculate great circle routes between points and provide latitude and longitude of corresponding rhumb line endpoints are quickly making this use of the gnomonic chart obsolete.

317. Stereographic Projection

A **stereographic projection** results from projecting points on the surface of the earth onto a tangent plane, from a point on the surface of the earth opposite the point of tangency (Figure 317a). This projection is also called an **azimuthal orthomorphic projection**.

The scale of the stereographic projection increases with distance from the point of tangency, but it increases more slowly than in the gnomonic projection. The stereographic projection can show an entire hemisphere without excessive distortion (Figure 317b). As in other azimuthal projections, great circles through the point of tangency ap-

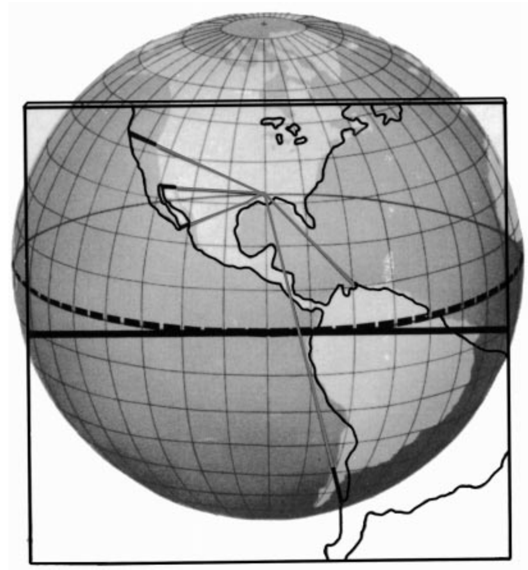


Figure 317a. An equatorial stereographic projection.

Figure 317b. A stereographic map of the Western Hemisphere.

pear as straight lines. Other circles such as meridians and parallels appear as either circles or arcs of circles.

The principal navigational use of the stereographic projection is for charts of the polar regions and devices for mechanical or graphical solution of the navigational triangle. A **Universal Polar Stereographic (UPS)** grid, mathematically adjusted to the graticule, is used as a reference system.

318. Orthographic Projection

If terrestrial points are projected geometrically from infinity to a tangent plane, an **orthographic projection** results (Figure 318a). This projection is not conformal; nor does it result in an equal area representation. Its principal use is in navigational astronomy because it is useful for illustrating and solving the navigational triangle. It is also useful for illustrating celestial coordinates. If the plane is tangent at a point on the equator, the parallels (including the equator) appear as straight lines. The meridians would appear as ellipses, except that the meridian through the point of tangency would appear as a straight line and the one 90° away would appear as a circle (Figure 318b).

319. Azimuthal Equidistant Projection

An **azimuthal equidistant projection** is an azimuthal projection in which the distance scale along any great circle through the point of tangency is constant. If a pole is the point of tangency, the meridians appear as straight radial lines and the parallels as equally spaced concentric circles. If the plane is tangent at some point other than a pole, the concentric circles represent distances from the point of tangency. In this case, meridians and parallels appear as curves.

The projection can be used to portray the entire earth, the point 180° from the point of tangency appearing as the largest of the concentric circles. The projection is not conformal, equal area, or perspective. Near the point of tangency distortion is small, increasing with distance until shapes near the opposite side of the earth are unrecognizable (Figure 319).

The projection is useful because it combines the three features of being azimuthal, having a constant distance scale from the point of tangency, and permitting the entire earth to be shown on one map. Thus, if an important harbor or airport is selected as the point of tangency, the great-circle course, distance, and track from that point to any other point on the earth are quickly and accurately determined. For communication work with the station at the point of tangency, the path of an incoming signal is at once apparent if the direction of arrival has been determined and the direction to train a directional antenna can be determined easily. The projection is also used for polar charts and for the star finder, No. 2102D.

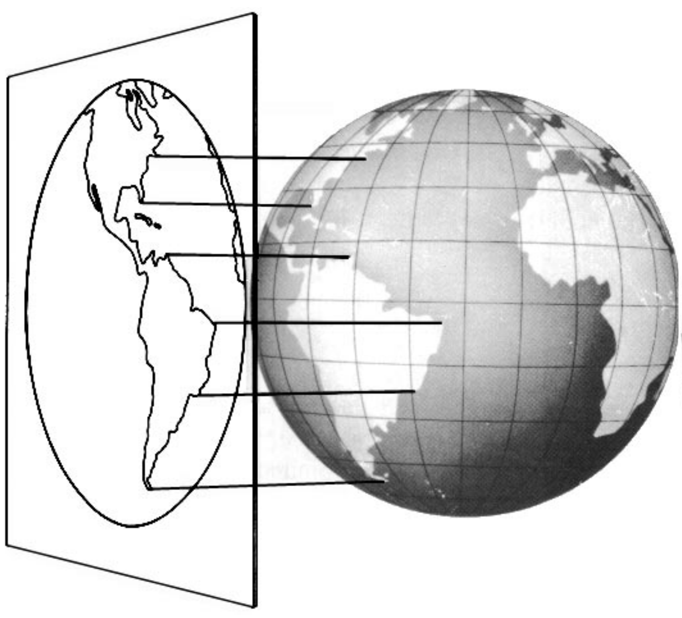


Figure 318a. An equatorial orthographic projection.

Figure 318b. An orthographic map of the Western Hemisphere.

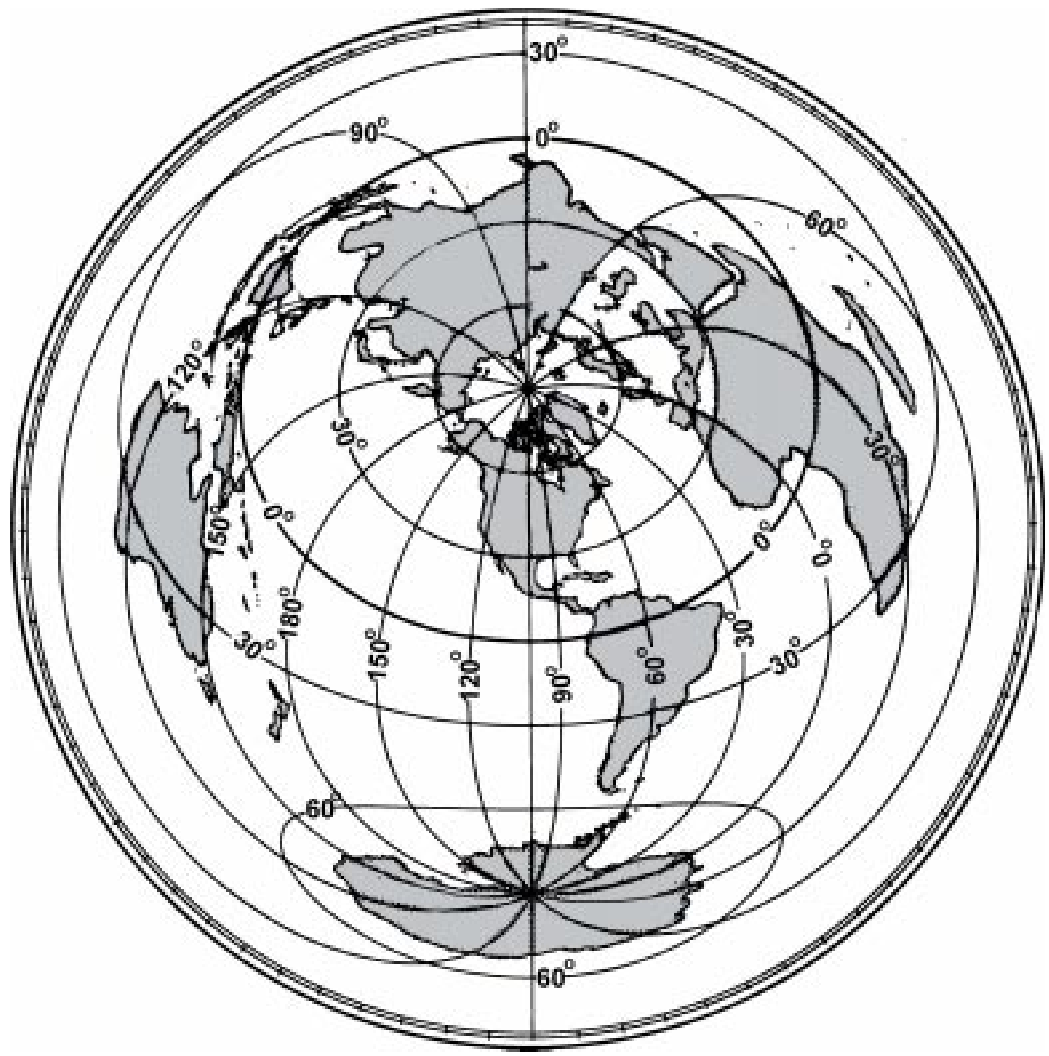


Figure 319. An azimuthal equidistant map of the world with the point of tangency latitude 40°N, longitude 100°W.

POLAR CHARTS

320. Polar Projections

Special consideration is given to the selection of projections for polar charts because the familiar projections become special cases with unique features.

In the case of cylindrical projections in which the axis of the cylinder is parallel to the polar axis of the earth, distortion becomes excessive and the scale changes rapidly. Such projections cannot be carried to the poles. However, both the transverse and oblique Mercator projections are used.

Conic projections with their axes parallel to the earth's polar axis are limited in their usefulness for polar charts because parallels of latitude extending through a full 360° of longitude appear as arcs of circles rather than full circles. This is because a cone, when cut along an element and flattened, does not extend through a full 360° without stretching or resuming its former conical shape. The usefulness of such projections is also limited by the fact that the pole appears as an arc of a circle instead of a point. However, by using a parallel very near the pole as the higher standard parallel, a conic projection with two standard parallels can be made. This requires little stretching to complete the circles of the parallels and eliminate that of the pole. Such a projection, called a **modified Lambert conformal** or **Ney's projection**, is useful for polar charts. It is particularly familiar to those accustomed to using the ordinary Lambert conformal charts in lower latitudes.

Azimuthal projections are in their simplest form when tangent at a pole. This is because the meridians are straight lines intersecting at the pole, and parallels are concentric circles with their common center at the pole. Within a few

degrees of latitude of the pole they all look similar; however, as the distance becomes greater, the spacing of the parallels becomes distinctive in each projection. In the polar azimuthal equidistant it is uniform; in the polar stereographic it increases with distance from the pole until the equator is shown at a distance from the pole equal to twice the length of the radius of the earth; in the polar gnomonic the increase is considerably greater, becoming infinity at the equator; in the polar orthographic it decreases with distance from the pole (Figure 320). All of these but the last are used for polar charts.

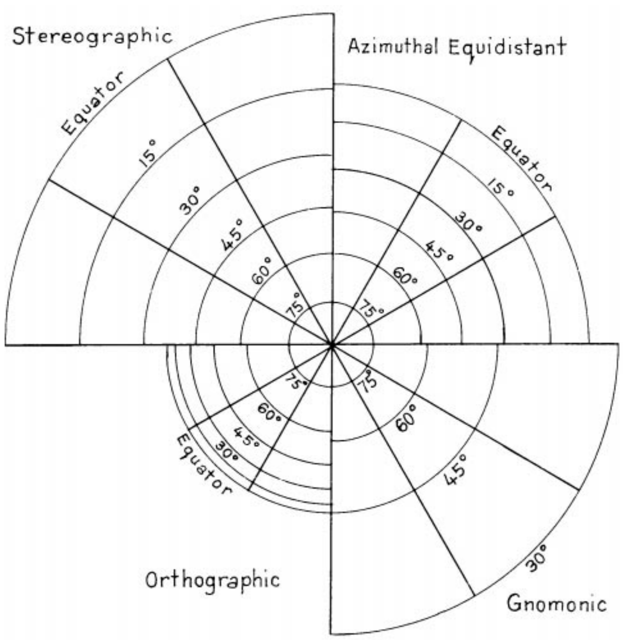


Figure 320. Expansion of polar azimuthal projections.

321. Selection Of A Polar Projection

The principal considerations in the choice of a suitable projection for polar navigation are:

1. Conformality: When the projection represents angles correctly, the navigator can plot directly on the chart.
2. Great circle representation: Because great circles are more useful than rhumb lines at high altitudes, the projection should represent great circles as straight lines.
3. Scale variation: The projection should have a constant scale over the entire chart.
4. Meridian representation: The projection should show straight meridians to facilitate plotting and grid navigation
5. Limits: Wide limits reduce the number of projections needed to a minimum.

The projections commonly used for polar charts are the modified Lambert conformal, gnomonic, stereographic, and azimuthal equidistant. All of these projections are similar near the pole. All are essentially conformal, and a great circle on each is nearly a straight line.

As the distance from the pole increases, however, the distinctive features of each projection become important. The modified Lambert conformal projection is virtually conformal over its entire extent. The amount of its scale distortion is comparatively little if it is carried only to about 25° or 30° from the pole. Beyond this, the distortion increases rapidly. A great circle is very nearly a straight line anywhere on the chart. Distances and directions can be measured directly on the chart in the same manner as on a Lambert conformal chart. However, because this projection is not strictly conformal, and on it great circles are not exactly represented by straight lines, it is not suited for highly accurate work.

The polar gnomonic projection is the one polar projection on which great circles are exactly straight lines. However, a complete hemisphere cannot be represented upon a plane because the radius of 90° from the center would become infinity.

The polar stereographic projection is conformal over its entire extent, and a straight line closely approximates a great circle. See Figure 321. The scale distortion is not excessive for a considerable distance from the pole, but it is greater than that of the modified Lambert conformal projection.

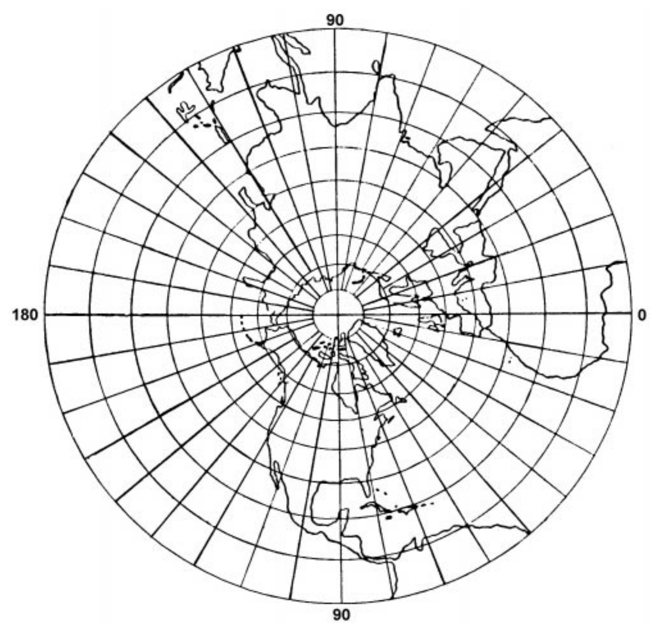


Figure 321. Polar stereographic projection.

The polar azimuthal equidistant projection is useful for showing a large area such as a hemisphere because there is

no expansion along the meridians. However, the projection is not conformal and distances cannot be measured accurately in any but a north-south direction. Great circles other than the meridians differ somewhat from straight lines. The equator is a circle centered at the pole.

The two projections most commonly used for polar charts are the modified Lambert conformal and the polar stereographic. When a directional gyro is used as a directional reference, the track of the craft is approximately a great circle. A desirable chart is one on which a great circle is represented as a straight line with a constant scale and with angles correctly represented. These requirements are not met entirely by any single projection, but they are approximated by both the modified Lambert conformal and the polar stereographic. The scale is more nearly constant on the former, but the projection is not strictly conformal. The polar stereographic is conformal, and its maximum scale variation can be reduced by using a plane which intersects the earth at some parallel intermediate between the pole and the lowest parallel. The portion within this standard parallel is compressed, and that portion outside is expanded.

The selection of a suitable projection for use in polar regions depends upon mission requirements. These requirements establish the relative importance of various features. For a relatively small area, any of several projections is suitable. For a large area, however, the choice is more difficult. If grid directions are to be used, it is important that all units in related operations use charts on the same projection, with the same standard parallels, so that a single grid direction exists between any two points. Nuclear powered submarine operations under the polar icecap have increased the need for grid directions in marine navigation.

SPECIAL CHARTS

322. Plotting Sheets

Position plotting sheets are “charts” designed primarily for open ocean navigation, where land, visual aids to navigation, and depth of water are not factors in navigation. They have a latitude and longitude graticule, and they may have one or more compass roses. The meridians are usually unlabeled, so a plotting sheet can be used for any longitude. Plotting sheets on Mercator projection are specific to latitude, and the navigator should have enough aboard for all latitudes for his voyage. Plotting sheets are less expensive than charts.

One use of a plotting sheet may occur in the event of an emergency when all charts have been lost or are otherwise unavailable. Directions on how to construct plotting sheets suitable for emergency purposes are given in Chapter 26, Emergency Navigation.

323. Grids

No system exists for showing the surface of the earth on a plane without distortion. Moreover, the appearance of the surface varies with the projection and with the relation of that surface area to the point of tangency. One may want to identify a location or area simply by alpha-numeric rectangular coordinates. This is accomplished with a **grid**. In its usual form this consists of two series of lines drawn perpendicularly on the chart, marked by suitable alpha-numeric designations.

A grid may use the rectangular graticule of the Mercator projection or a set of arbitrary lines on a particular projection. **The World Geodetic Reference System (GEOREF)** is a method of designating latitude and longitude by a system of letters and numbers instead of by angular measure. It is not, therefore, strictly a grid. It is useful for operations extending over a wide area. Examples of the second type of grid are the **Universal Transverse Mercator (UTM)** grid, the **Universal Polar Stereographic (UPS)** grid, and the **Temporary Geographic Grid (TGG)**. Since these systems are used primarily by military forces, they are sometimes called military grids.

CHART SCALES

324. Types Of Scales

The **scale** of a chart is the ratio of a given distance on the chart to the actual distance which it represents on the earth. It may be expressed in various ways. The most common are:

1. A simple ratio or fraction, known as the **representative fraction**. For example, 1:80,000 or 1/80,000 means that one unit (such as a meter) on the chart represents 80,000 of the same unit on the surface of the earth. This scale is sometimes called the **natural** or **fractional** scale.
2. A **statement** that a given distance on the earth equals a given measure on the chart, or vice versa. For example, “30 miles to the inch” means that 1 inch on the chart represents 30 miles of the earth’s surface. Similarly, “2 inches to a mile” indicates that 2 inches on the chart represent 1 mile on the earth. This is sometimes called the **numerical scale**.
3. A line or bar called a **graphic scale** may be drawn at a convenient place on the chart and subdivided into nautical miles, meters, etc. All charts vary somewhat

in scale from point to point, and in some projections the scale is not the same in all directions about a single point. A single subdivided line or bar for use over an entire chart is shown only when the chart is of such scale and projection that the scale varies a negligible amount over the chart, usually one of about 1:75,000 or larger. Since 1 minute of latitude is very nearly equal to 1 nautical mile, the latitude scale serves as an approximate graphic scale. On most nautical charts the east and west borders are subdivided to facilitate distance measurements.

On a Mercator chart the scale varies with the latitude. This is noticeable on a chart covering a relatively large distance in a north-south direction. On such a chart the border scale near the latitude in question should be used for measuring distances.

Of the various methods of indicating scale, the graphical method is normally available in some form on the chart. In addition, the scale is customarily stated on charts on which the scale does not change appreciably over the chart.

The ways of expressing the scale of a chart are readily interchangeable. For instance, in a nautical mile there are about 72,913.39 inches. If the natural scale of a chart is 1:80,000, one inch of the chart represents 80,000 inches of the earth, or a little more than a mile. To find the exact amount, divide the scale by the number of inches in a mile, or 80,000/72,913.39 = 1.097. Thus, a scale of 1:80,000 is the same as a scale of 1.097 (or approximately 1.1) miles to an inch. Stated another way, there are: 72,913.39/80,000 = 0.911 (approximately 0.9) inch to a mile. Similarly, if the scale is 60 nautical miles to an inch, the representative fraction is 1:(60 x 72,913.39) = 1:4,374,803.

A chart covering a relatively large area is called a **small-scale chart** and one covering a relatively small area is called a **large-scale chart**. Since the terms are relative, there is no sharp division between the two. Thus, a chart of scale 1:100,000 is large scale when compared with a chart of 1:1,000,000 but small scale when compared with one of 1:25,000.

As scale decreases, the amount of detail which can be shown decreases also. Cartographers selectively decrease the detail in a process called **generalization** when producing small scale charts using large scale charts as sources. The amount of detail shown depends on several factors, among them the coverage of the area at larger scales and the intended use of the chart.

325. Chart Classification By Scale

Charts are constructed on many different scales, ranging from about 1:2,500 to 1:14,000,000. Small-scale charts covering large areas are used for route planning and for offshore navigation. Charts of larger scale, covering smaller areas, are used as the vessel approaches land. Several methods of classifying charts according to scale are used in various nations. The following classifications of nautical charts are used by the National Ocean Service.

Sailing charts are the smallest scale charts used for planning, fixing position at sea, and for plotting the dead reckoning while proceeding on a long voyage. The scale is generally smaller than 1:600,000. The shoreline and topography are generalized and only offshore soundings, the principal navigational lights, outer buoys, and landmarks visible at considerable distances are shown.

General charts are intended for coastwise navigation outside of outlying reefs and shoals. The scales range from about 1:150,000 to 1:600,000.

Coastal charts are intended for inshore coastwise navigation, for entering or leaving bays and harbors of considerable width, and for navigating large inland waterways. The scales range from about 1:50,000 to 1:150,000.

Harbor charts are intended for navigation and anchorage in harbors and small waterways. The scale is generally larger than 1:50,000.

In the classification system used by the Defense Mapping Agency Hydrographic/Topographic Center, the sailing charts are incorporated in the general charts classification (smaller than about 1:150,000); those coast charts especially useful for approaching more confined waters (bays, harbors) are classified as approach charts. There is considerable overlap in these designations, and the classification of a chart is best determined by its use and by its relationship to other charts of the area. The use of insets complicates the placement of charts into rigid classifications.

CHART ACCURACY

326. Factors Relating To Accuracy

The accuracy of a chart depends upon the accuracy of the hydrographic surveys used to compile it and the suitability of its scale for its intended use.

Estimate the accuracy of a chart’s surveys from the source notes given in the title of the chart. If the chart is based upon very old surveys, use it with caution. Many early surveys were inaccurate because of the technological limitations of the surveyor.

The number of soundings and their spacing indicates the completeness of the survey. Only a small fraction of the soundings taken in a thorough survey are shown on the chart, but sparse or unevenly distributed soundings indicate that the survey was probably not made in detail. See Figure 326a and Figure 326b Large blank areas or absence of depth

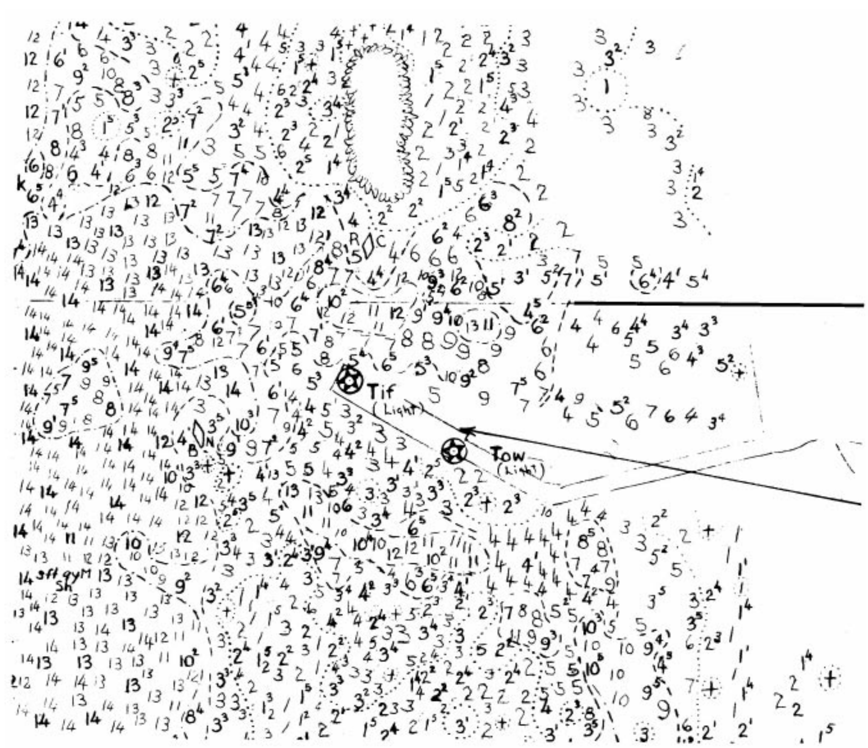


Figure 326a. Part of a “boat sheet,” showing the soundings obtained in a survey.

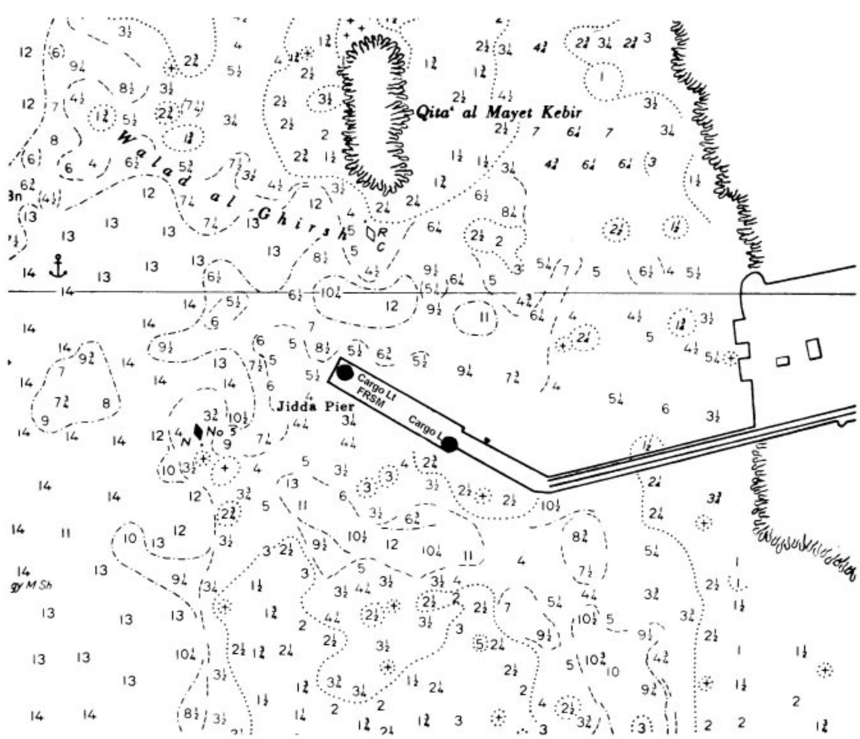


Figure 326b. Part of a nautical chart made from the boat sheet of Figure 326a. Compare the number of soundings in the two figures.

contours generally indicate lack of soundings in the area. Operate in an area with sparse sounding data only if operationally required and then only with the most extreme caution. Run the echo sounder continuously and operate at a reduced speed. Sparse sounding information does not necessarily indicate an incomplete survey. Relatively few soundings are shown when there is a large number of depth contours, or where the bottom is flat, or gently and evenly sloping. Additional soundings are shown when they are helpful in indicating the uneven character of a rough bottom.

Even a detailed survey may fail to locate every rock or pinnacle. In waters where they might be located, the best method for finding them is a wire drag survey. Areas that have been dragged may be indicated on the chart by limiting lines and green or purple tint and a note added to show the effective depth at which the drag was operated.

Changes in bottom contours are relatively rapid in areas such as entrances to harbors where there are strong currents or heavy surf. Similarly, there is sometimes a tendency for dredged channels to shoal, especially if they are surrounded by sand or mud, and cross currents exist. Charts often contain notes indicating the bottom contours are known to change rapidly.

The same detail cannot be shown on a small-scale chart as on a large scale chart. On small-scale charts, detailed information is omitted or "generalized" in the areas covered by larger scale charts. The navigator should use the largest scale chart available for the area in which he is operating, especially when operating in the vicinity of hazards.

Charting agencies continually evaluate both the detail and the presentation of data appearing on a chart. Development of a new navigational aid may render previous charts inadequate. The development of radar, for example, required upgrading charts which lacked the detail required for reliable identification of radar targets.

After receiving a chart, the user is responsible for keeping it updated. Mariners reports of errors, changes, and suggestions are useful to charting agencies. Even with modern automated data collection techniques, there is no substitute for on-sight observation of hydrographic conditions by experienced mariners. This holds true especially in less frequently traveled areas of the world.

CHART READING

327. Chart Dates

NOS charts have two dates. At the top center of the chart is the date of the *first edition* of the chart. In the lower left corner of the chart is the *current* edition number and date. This date shows the latest date through which Notice to Mariners were applied to the chart. Any subsequent change will be printed in the Notice to Mariners. Any notices which accumulate between the chart date and the announcement date in the Notice to Mariners will be given with the announcement. Comparing the dates of the first and current editions gives an indication of how often thechart is updated. Charts of busy areas are updated more frequently than those of less traveled areas. This interval may vary from 6 months to more than ten years for NOS charts. This update interval may be much longer for certain DMAHTC charts in remote areas.

New editions of charts are both demand and source driven. Receiving significant new information may or may not initiate a new edition of a chart, depending on the demand for that chart. If it is in a sparsely-traveled area, other priorities may delay a new edition for several years. Conversely, a new edition may be printed without the receipt of significant new data if demand for the chart is high and stock levels are low. Notice to Mariners corrections are always included on new editions.

DMAHTC charts have the same two dates as the NOS charts; the current chart edition number and date is given in the lower left corner. Certain DMAHTC charts are reproductions of foreign charts produced under joint agreements with a number of other countries. These charts, even though of recent date, may be based on foreign charts of considerably earlier date. Further, new editions of the foreign chart will not necessarily result in a new edition of the DMAHTC reproduction. In these cases, the foreign chart is the better chart to use.

A **revised** or **corrected print** contains corrections which have been published in Notice to Mariners. These corrected prints do not supersede a current edition. The date of the revision is given, along with the latest Notice to Mariners to which the chart has been corrected.

328. Title Block

See Figure 328. The chart title block should be the first thing a navigator looks at when receiving a new edition chart. The title itself tells what area the chart covers. The chart's scale and projection appear below the title. The chart will give both vertical and horizontal datums and, if necessary, a datum conversion note. Source notes or diagrams will list the date of surveys and other charts used in compilation.

329. Shoreline

The shoreline shown on nautical charts represents the

BALTIC SEA

GERMANY—NORTH COAST

DAHMESHÖVED TO WISMAR

From German Surveys

SOUNDINGS IN METERS

reduced to the approximate level of Mean Sea Level

HEIGHTS IN METERS ABOVE MEAN SEA LEVEL

MERCATOR PROJECTION

EUROPEAN DATUM

SCALE 1:50,000

Figure 328. A chart title block.

line of contact between the land and water at a selected vertical datum. In areas affected by tidal fluctuations, this is usually the mean high-water line. In confined coastal waters of diminished tidal influence, a mean water level line may be used. The shoreline of interior waters (rivers, lakes) is usually a line representing a specified elevation above a selected datum. A shoreline is symbolized by a heavy line. A broken line indicates that the charted position is approximate only. The nature of the shore may be indicated.

If the low water line differs considerably from the high water line, then a dotted line represents the low water line. If the bottom in this area is composed of mud, sand, gravel or stones, the type of material will be indicated. If the bottom is composed of coral or rock, then the appropriate symbol will be used. The area alternately covered and uncovered may be shown by a tint which is usually a combination of the land and water tint.

The apparent shoreline shows the outer edge of marine vegetation where that limit would appear as shoreline to the mariner. It is also used to indicate where marine vegetation prevents the mariner from defining the shoreline. A light line symbolizes this shoreline. A broken line marks the inner edge when no other symbol (such as a cliff or levee) furnishes such a limit. The combined land-water tint or the land tint marks the area between inner and outer limits.

330. Chart Symbols

Much of the information contained on charts is shown by symbols. These symbols are not shown to scale, but they indicate the correct position of the feature to which they refer. The standard symbols and abbreviations used on charts published by the United States of America are shown in ***Chart No. 1, Nautical Chart Symbols and Abbreviations***. See Figure 330.

Electronic chart symbols are, within programming and display limits, much the same as printed ones. The less expensive electronic charts have less extensive symbol libraries, and the screen’s resolution may affect the presentation detail.

Most of the symbols and abbreviations shown in U.S. Chart No. 1 agree with recommendations of the International Hydrographic Organization (IHO). The layout is explained in the general remarks section of Chart No. 1.

The symbols and abbreviations on any given chart may differ somewhat from those shown in Chart No. 1. In addition, foreign charts may use different symbology. When using a foreign chart, the navigator should have available the Chart No. 1 from the country which produced the chart.

Chart No. 1 is organized according to subject matter, with each specific subject given a letter designator. The general subject areas are General, Topography, Hydrography, Aids and Services, and Indexes. Under each heading, letter designators further define subject areas, and individual numbers refer to specific symbols.

Information in Chart No. 1 is arranged in columns. The first column contains the IHO number code for the symbol in question. The next two columns show the symbol itself, in NOS and NIMAformats. If the formats are the same, the two columns are combined into one. The next column is a text description of the symbol, term, or abbreviation. The next column contains the IHO standard symbol. The last column shows certain symbols used on foreign reproduction charts produced by NIMA.

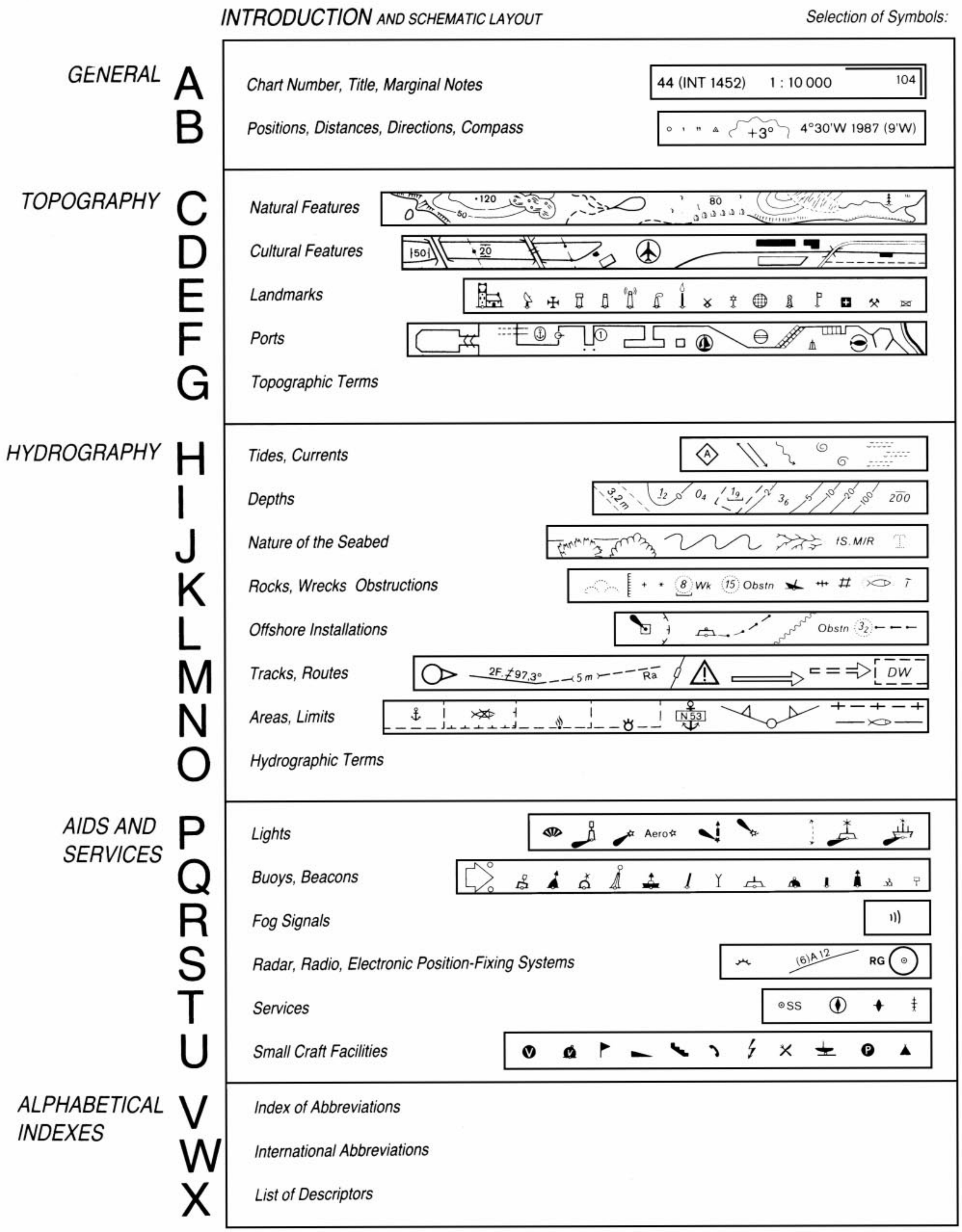


Figure 330. Contents of U.S. Chart No. 1.

331. Lettering

Except on some modified reproductions of foreign charts, cartographers have adopted certain lettering standards. Vertical type is used for features which are dry at high water and not affected by movement of the water; slanting type is used for underwater and floating features.

There are two important exceptions to the two general rules listed above. Vertical type is not used to represent heights above the waterline, and slanting type is not used to indicate soundings, except on metric charts. Section 332 below discusses the conventions for indicating soundings.

Evaluating the type of lettering used to denote a feature, one can determine whether a feature is visible at high tide. For instance, a rock might bear the title “ Rock” whether or not it extends above the surface. If the name is given in vertical letters, the rock constitutes a small islet; if in slanting type, the rock constitutes a reef, covered at high water.

332. Soundings

Charts show soundings in several ways. Numbers denote individual soundings. These numbers may be either vertical or slanting; both may be used on the same chart, distinguishing between data based upon different U.S. and foreign surveys, different datums, or smaller scale charts.

Large block letters at the top and bottom of the chart indicate the unit of measurement used for soundings. SOUNDINGS IN FATHOMS indicates soundings are in fathoms or fathoms and fractions. SOUNDINGS IN FATHOMS AND FEET indicates the soundings are in fathoms and feet. A similar convention is followed when the soundings are in meters or meters and tenths.

A **depth conversion scale** is placed outside the neatline on the chart for use in converting charted depths to feet, meters, or fathoms. “No bottom” soundings are indicated by a number with a line over the top and a dot over the line. This indicates that the spot was sounded to the depth indicated without reaching the bottom. Areas which have been wire dragged are shown by a broken limiting line, and the clear effective depth is indicated, with a characteristic symbol under the numbers. On NIMA charts a purple or green tint is shown within the swept area.

Soundings are supplemented by **depth contours**, lines connecting points of equal depth. These lines present a picture of the bottom. The types of lines used for various depths are shown in Section I of Chart No. 1. On some charts depth contours are shown in solid lines; the depth represented by each line is shown by numbers placed in breaks in the lines, as with land contours. Solid line depth contours are derived from intensively developed hydrographic surveys. A broken or indefinite contour is substituted for a solid depth contour whenever the reliability of the contour is questionable.

Depth contours are labeled with numerals in the unit of measurement of the soundings. A chart presenting a more detailed indication of the bottom configuration with fewer numerical soundings is useful when bottom contour navigating. Such a chart can be made only for areas which have undergone a detailed survey

Shoal areas often are given a blue tint. Charts designed to give maximum emphasis to the configuration of the bottom show depths beyond the 100-fathom curve over the entire chart by depth contours similar to the contours shown on land areas to indicate graduations in height. These are called **bottom contour** or **bathymetric charts**.

On electronic charts, a variety of other color schemes may be used, according to the manufacturer of the system. Color perception studies are being used to determine the best presentation.

The side limits of dredged channels are indicated by broken lines. The project depth and the date of dredging, if known, are shown by a statement in or along the channel. The possibility of silting is always present. Local authorities should be consulted for the controlling depth. NOS Charts frequently show controlling depths in a table, which is kept current by the Notice to Mariners.

The chart scale is generally too small to permit all soundings to be shown. In the selection of soundings, least depths are shown first. This conservative sounding pattern provides safety and ensures an uncluttered chart appearance. Steep changes in depth may be indicated by more dense soundings in the area. The limits of shoal water indicated on the chart may be in error, and nearby areas of undetected shallow water may not be included on the chart. Given this possibility, areas where shoal water is known to exist should be avoided. If the navigator must enter an area containing shoals, he must exercise extreme caution in avoiding shallow areas which may have escaped detection. By constructing a “safety range” around known shoals and ensuring his vessel does not approach the shoal any closer than the safety range, the navigator can increase his chances of successfully navigating through shoal water. Constant use of the echo sounder is also important.

333. Bottom Description

Abbreviations listed in Section J of Chart No. 1 are used to indicate what substance forms the bottom. The meaning of these terms can be found in the Glossary of Marine Navigation. Knowing the characteristic of the bottom is most important when anchoring.

334. Depths And Datums

Depths are indicated by soundings or explanatory notes. Only a small percentage of the soundings obtained in a hydrographic survey can be shown on a nautical chart. The least depths are generally selected first, and a pattern built around them to provide a representative indication of bottom relief. In shallow water, soundings may be spaced 0.2 to 0.4 inch apart. The spacing is gradually increased as water deepens, until a spacing of 0.8 to 1.0 inch is reached in deeper waters offshore. Where a sufficient number of soundings are available to permit adequate interpretation,

depth curves are drawn in at selected intervals.

All depths indicated on charts are reckoned from a selected level of the water, called the **chart sounding datum**. The various chart datums are explained in Chapter 9, Tides and Tidal Currents. On charts made from surveys conducted by the United States, the chart datum is selected with regard to the tides of the region. Depths shown are the least depths to be expected under average conditions. On charts based on foreign charts and surveys the datum is that of the original authority. When it is known, the datum used is stated on the chart. In some cases where the chart is based upon old surveys, particularly in areas where the range of tide is not great, the sounding datum may not be known.

For most National Ocean Service charts of the United States and Puerto Rico, the chart datum is mean lower low water. Most Defense Mapping Agency Hydrographic/Topographic Center charts are based upon mean low water, mean lower low water, or mean low water springs. The chart datum for charts published by other countries varies greatly, but is usually lower than mean low water. On charts of the Baltic Sea, Black Sea, the Great Lakes, and other areas where tidal effects are small or without significance, the datum adopted is an arbitrary height approximating the mean water level.

The chart datum of the largest scale chart of an area is generally the same as the reference level from which height of tide is tabulated in the tide tables.

The chart datum is usually only an approximation of the actual mean value, because determination of the actual mean height usually requires a longer series of tidal observations than is usually available to the cartographer. In addition, the heights of the tide vary as a function of time.

Since the chart datum is generally a computed mean or average height at some state of the tide, the depth of water at any particular moment may be less than shown on the chart. For example, if the chart datum is mean lower low water, the depth of water at lower low water will be less than the charted depth about as often as it is greater. A lower depth is indicated in the tide tables by a minus sign (–).

335. Heights

The shoreline shown on charts is generally mean high water. A light's height is usually reckoned from mean sea level. The heights of overhanging obstructions (bridges, power cables, etc.) are usually reckoned from mean high water. A high water reference gives the mariner the minimum clearance expected.

Since heights are usually reckoned from high water and depths from some form of low water, the reference levels are seldom the same. Except where the range of tide is very large, this is of little practical significance.

336. Dangers

Dangers are shown by appropriate symbols, as indicated in Section K of Chart No. 1.

A rock uncovered at mean high water may be shown as an islet. If an isolated, offlying rock is known to uncover at the sounding datum but to be covered at high water, the chart shows the appropriate symbol for a rock and gives the height above the sounding datum. The chart can give this height one of two ways. It can use a statement such as "Uncov 2 ft.," or it can indicate the number of feet the rock protrudes above the sounding datum, underline this value, and enclose it in parentheses (i.e. ($\underline{2}$)). A rock which does not uncover is shown by an enclosed figure approximating its dimensions and filled with land tint. It may be enclosed by a dotted depth curve for emphasis.

A tinted, irregular-line figure of approximately true dimensions is used to show a detached coral reef which uncovers at the chart datum. For a coral or rocky reef which is submerged at chart datum, the sunken rock symbol or an appropriate statement is used, enclosed by a dotted or broken line if the limits have been determined.

Several different symbols mark wrecks. The nature of the wreck or scale of the chart determines the correct symbol. A sunken wreck with less than 11 fathoms of water over it is considered dangerous and its symbol is surrounded by a dotted curve. The curve is omitted if the wreck is deeper than 11 fathoms. The safe clearance over a wreck, if known, is indicated by a standard sounding number placed at the wreck. If this depth was determined by a wire drag, the sounding is underscored by the wire drag symbol. An unsurveyed wreck over which the exact depth is unknown but a safe clearance depth is known is depicted with a solid line above the symbol.

Tide rips, eddies, and kelp are shown by symbol or legend.

Piles, dolphins (clusters of piles), snags, and stumps are shown by small circles and a label identifying the type of obstruction. If such dangers are submerged, the letters "Subm" precede the label.

Fish stakes and traps are shown when known to be permanent or hazardous to navigation.

337. Aids To Navigation

Aids to navigation are shown by symbols listed in Sections P through S of Chart No. 1. Abbreviations and additional descriptive text supplement these symbols. In order to make the symbols conspicuous, the chart shows them in size greatly exaggerated relative to the scale of the chart. "Position approximate" circles are used on floating aids to indicate that they have no exact position because they move around their moorings. For most floating aids, the position circle in the symbol marks the approximate location of the anchor or sinker. The actual aid may be displaced from this location by the scope of its mooring.

The type and number of aids to navigation shown on a chart and the amount of information given in their legends varies with the scale of the chart. Smaller scale charts may have fewer aids indicated and less information than larger

scale charts of the same area.

Lighthouses and other navigation lights are shown as black dots with purple disks or as black dots with purple flare symbols. The center of the dot is the position of the light. Some modified facsimile foreign charts use a small star instead of a dot.

On large-scale charts the legend elements of lights are shown in the following order:

Legend	*Example*	*Meaning*
Characteristic	F1(2)	group flashing; 2 flashes
Color	R	red
Period	10s	2 flashes in 10 seconds
Height	80m	80 meters
Range	19M	19 nautical miles
Designation	"6"	light number 6

The legend for this light would appear on the chart:

Fl(2) R 10s 80m 19M "6"

As chart scale decreases, information in the legend is selectively deleted to avoid clutter. The order of deletion is usually height first, followed by period, group repetition interval (e.g. (2)), designation, and range. Characteristic and color will almost always be shown.

Small triangles mark red daybeacons; small squares mark all others. On NIMA charts, pictorial beacons are used when the IALA buoyage system has been implemented. The center of the triangle marks the position of the aid. Except on Intracoastal Waterway charts and charts of state waterways, the abbreviation "Bn" is shown beside the symbol, along with the appropriate abbreviation for color if known. For black beacons the triangle is solid black and there is no color abbreviation. All beacon abbreviations are in vertical lettering.

Radiobeacons are indicated on the chart by a purple circle accompanied by the appropriate abbreviation indicating an ordinary radiobeacon (R Bn) or a radar beacon (Ramark or Racon, for example).

A variety of symbols, determined by both the charting agency and the types of buoys, indicate navigation buoys. IALA buoys (see Chapter 5, Short Range Aids to Navigation) in foreign areas are depicted by various styles of symbols with proper topmarks and colors; the position circle which shows the approximate location of the sinker is at the base of the symbol.

A mooring buoy is shown by one of several symbols as indicated in Chart No. 1. It may be labeled with a berth number or other information.

A buoy symbol with a horizontal line indicates the buoy has horizontal bands. A vertical line indicates vertical stripes; crossed lines indicate a checked pattern. There is no significance to the angle at which the buoy symbol appears on the chart. The symbol is placed so as to avoid interference with other features.

Lighted buoys are indicated by a purple flare from the buoy symbol or by a small purple disk centered on the position circle.

Abbreviations for light legends, type and color of buoy, designation, and any other pertinent information given near the symbol are in slanted type. The letter C, N, or S indicates a can, nun, or spar, respectively. Other buoys are assumed to be pillar buoys, except for special buoys such as spherical, barrel, etc. The number or letter designation of the buoy is given in quotation marks on NOS charts. On other charts they may be given without quotation marks or other punctuation.

Aeronautical lights included in the light lists are shown by the lighthouse symbol, accompanied by the abbreviation "AERO." The characteristics shown depend principally upon the effective range of other navigational lights in the vicinity and the usefulness of the light for marine navigation.

Directional ranges are indicated by a broken or solid line. The solid line, indicating that part of the range intended for navigation, may be broken at irregular intervals to avoid being drawn through soundings. That part of the range line drawn only to guide the eye to the objects to be kept in range is broken at regular intervals. The direction, if given, is expressed in degrees, clockwise from true north.

Sound signals are indicated by the appropriate word in capital letters (HORN, BELL, GONG, or WHIS) or an abbreviation indicating the type of sound. Sound signals of any type except submarine sound signals may be represented by three purple 45° arcs of concentric circles near the top of the aid. These are not shown if the type of signal is listed. The location of a sound signal which does not accompany a visual aid, either lighted or unlighted, is shown by a small circle and the appropriate word in vertical block letters.

Private aids, when shown, are marked "Priv" on NOS charts. Some privately maintained unlighted fixed aids are indicated by a small circle accompanied by the word "Marker," or a larger circle with a dot in the center and the word "MARKER." A privately maintained lighted aid has a light symbol and is accompanied by the characteristics and the usual indication of its private nature. Private aids should be used with caution.

A light sector is the sector or area bounded by two radii and the arc of a circle in which a light is visible or in which it has a distinctive color different from that of adjoining sectors. The limiting radii are indicated on the chart by dotted or dashed lines. Sector colors are indicated by words spelled out if space permits, or by abbreviations (W, R, etc.) if it does not. Limits of light sectors and arcs of visibility as observed from a vessel are given in the light lists, in clockwise order.

338. Land Areas

The amount of detail shown on the land areas of nautical charts depends upon the scale and the intended purpose of the chart. Contours, form lines, and shading indicate relief.

Contours are lines connecting points of equal elevation. Heights are usually expressed in feet (or in meters with means for conversion to feet). The interval between contours is uniform over any one chart, except that certain intermediate contours are sometimes shown by broken line. When contours are broken, their locations are approximate.

Form lines are approximations of contours used for the purpose of indicating relative elevations. They are used in areas where accurate information is not available in sufficient detail to permit exact location of contours. Elevations of individual form lines are not indicated on the chart.

Spot elevations are generally given only for summits or for tops of conspicuous landmarks. The heights of spot elevations and contours are given with reference to mean high water when this information is available.

When there is insufficient space to show the heights of islets or rocks, they are indicated by slanting figures enclosed in parentheses in the water area nearby.

339. Cities And Roads

Cities are shown in a generalized pattern that approximates their extent and shape. Street names are generally not charted except those along the waterfront on the largest scale charts. In general, only the main arteries and thoroughfares or major coastal highways are shown on smaller scale charts. Occasionally, highway numbers are given. When shown, trails are indicated by a light broken line. Buildings along the waterfront or individual ones back from the waterfront but of special interest to the mariner are shown on large-scale charts. Special symbols from Chart No. 1 are used for certain kinds of buildings. A single line with cross marks indicates both single and double track railroads. City electric railways are usually not charted. Airports are shown on small-scale charts by symbol and on large-scale charts by the shape of runways. The scale of the chart determines if single or double lines show breakwaters and jetties; broken lines show the submerged portion of these features.

340. Landmarks

Landmarks are shown by symbols in Chart No. 1.

A large circle with a dot at its center is used to indicate that the position is precise and may be used without reservation for plotting bearings. A small circle without a dot is used for landmarks not accurately located. Capital and lower case letters are used to identify an approximate landmark: “Mon,” “Cup,” or “Dome.” The abbreviation “PA” (position approximate) may also appear. An accurate landmark is identified by all capital type (“MON,” “CUP,” “DOME”).

When only one object of a group is charted, its name is followed by a descriptive legend in parenthesis, including the number of objects in the group, for example “(TALLEST OF FOUR)”or “(NORTHEAST OF THREE).”

341. Miscellaneous Chart Features

A measured nautical mile indicated on a chart is accurate to within 6 feet of the correct length. Most measured miles in the United States were made before 1959, when the United States adopted the International Nautical Mile. The new value is within 6 feet of the previous standard length of 6,080.20 feet. If the measured distance differs from the standard value by more than 6 feet, the actual measured distance is stated and the words “measured mile” are omitted.

Periods after abbreviations in water areas are omitted because these might be mistaken for rocks. However, a lower case i or j is dotted.

Commercial radio broadcasting stations are shown on charts when they are of value to the mariner either as landmarks or sources of direction-finding bearings.

Lines of demarcation between the areas in which international and inland navigation rules apply are shown only when they cannot be adequately described in notes on the chart.

Compass roses are placed at convenient locations on Mercator charts to facilitate the plotting of bearings and courses. The outer circle is graduated in degrees with zero at true north. The inner circle indicates magnetic north.

On many NIMA charts magnetic variation is given to the nearest 1' by notes in the centers of compass roses; the annual change is given to the nearest 1' to permit correction of the given value at a later date. On NOS charts, variation is to the nearest 15', updated at each new edition if over three years old. The current practice of NIMA is to give the magnetic variation to the nearest 1', but the magnetic information on new editions is only updated to conform with the latest five year epoch. Whenever a chart is reprinted, the magnetic information is updated to the latest epoch. On other charts, the variation is given by a series of isogonic lines connecting points of equal variation; usually a separate line represents each degree of variation. The line of zero variation is called the agonic line. Many plans and insets show neither compass roses nor isogonic lines, but indicate magnetic information by note. A local magnetic disturbance of sufficient force to cause noticeable deflection of the magnetic compass, called local attraction, is indicated by a note on the chart.

Currents are sometimes shown on charts with arrows giving the directions and figures showing speeds. The information refers to the usual or average conditions. According to tides and weather, conditions at any given time may differ considerably from those shown.

Review chart notes carefully because they provide important information. Several types of notes are used. Those in the margin give such information as chart number, pub-

lication notes, and identification of adjoining charts. Notes in connection with the chart title include information on scale, sources of data, tidal information, soundings, and cautions. Another class of notes covers such topics as local magnetic disturbance, controlling depths of channels, hazards to navigation, and anchorages.

A datum note will show the datum of the chart (See Chapter 2, Geodesy and Datums in Navigation). It may also contain instructions on plotting positions from the WGS 84 or NAD 83 datums on the chart if such a conversion is needed.

Anchorage areas are labeled with a variety of magenta, black, or green lines depending on the status of the area. Anchorage berths are shown as purple circles, with the number or letter assigned to the berth inscribed within the circle. Caution notes are sometimes shown when there are specific anchoring regulations.

Spoil areas are shown within short broken black lines. Spoil areas are tinted blue on NOS charts and labeled. These areas contain no soundings and should be avoided.

Firing and bombing practice areas in the United States territorial and adjacent waters are shown on NOS and NIMA charts of the same area and comparable scale.

Danger areas established for short periods of time are not charted but are announced locally. Most military commands charged with supervision of gunnery and missile firing areas promulgate a weekly schedule listing activated danger areas. This schedule is subjected to frequent change; the mariner should always ensure he has the latest schedule prior to proceeding into a gunnery or missile firing area. Danger areas in effect for longer periods are published in the Notice to Mariners. Any aid to navigation established to mark a danger area or a fixed or floating target is shown on charts.

Traffic separation schemes are shown on standard nautical charts of scale 1:600,000 and larger and are printed in magenta.

A logarithmic time-speed-distance nomogram with an explanation of its application is shown on harbor charts.

Tidal information boxes are shown on charts of scales 1:200,000 and larger for NOS charts, and various scales on DMA charts, according to the source. See Figure 341a.

Tabulations of controlling depths are shown on some National Ocean Service harbor and coastal charts. See Figure 341b.

Study Chart No. 1 thoroughly to become familiar with all the symbols used to depict the wide variety of features on nautical charts.

TIDAL INFORMATION

Place	Position		Height above datum of soundings			
			Mean High Water		Mean Low Water	
	N. Lat.	E. Long.	Higher	Lower	Lower	Higher
			meters	meters	meters	meters
Olongapo	14˚49'	120˚17'	. . . 0.9 . . .	. . . 0.4 . . .	. . . 0.0 . . .	. . . 0.3 . . .

Figure 341a. Tidal box.

NANTUCKET HARBOR

Tabulated from surveys by the Corps of Engineers - report of June 1972 and surveys of Nov. 1971

Controlling depths in channels entering from seaward in feet at Mean Low Water					Project Dimensions		
Name of Channel	Left outside quarter	Middle half of channel	Right outside quarter	Date of Survey	Width (feet)	Length (naut. miles)	Depth M. L. W. (feet)
Entrance Channel	**11.1**	**15.0**	**15.0**	11 - 71	300	1.2	15

Note.-The Corps of Engineers should be consulted for changing conditions subsequent to the above.

Figure 341b. Tabulations of controlling depths.

REPRODUCTIONS OF FOREIGN CHARTS

342. Modified Facsimiles

Modified facsimile charts are modified reproductions of foreign charts produced in accordance with bilateral international agreements. These reproductions provide the mariner with up-to-date charts of foreign waters. Modified facsimile charts published by DMAHTC are, in general, reproduced with minimal changes, as listed below:

1. The original name of the chart may be removed and replaced by an anglicized version.
2. English language equivalents of names and terms on the original chart are printed in a suitable glossary on the reproduction, as appropriate.
3. All hydrographic information, except bottom characteristics, is shown as depicted on the original chart.
4. Bottom characteristics are as depicted in Chart No. 1, or as on the original with a glossary.
5. The unit of measurement used for soundings is shown in block letters outside the upper and lower neatlines.
6. A scale for converting charted depth to feet, meters, or fathoms is added.
7. Blue tint is shown from a significant depth curve to the shoreline.
8. Blue tint is added to all dangers enclosed by a dotted danger curve, dangerous wrecks, foul areas, obstructions, rocks awash, sunken rocks, and swept wrecks.
9. Caution notes are shown in purple and enclosed in a box.
10. Restricted, danger, and prohibited areas are usually outlined in purple and labeled appropriately.
11. Traffic separation schemes are shown in purple.
12. A note on traffic separation schemes, printed in black, is added to the chart.
13. Wire dragged (swept) areas are shown in purple or green.
14. Corrections are provided to shift the horizontal datum to the World Geodetic System (1984).

INTERNATIONAL CHARTS

343. International Chart Standards

The need for mariners and chart makers to understand and use nautical charts of different nations became increasingly apparent as the maritime nations of the world developed their own establishments for the compilation and publication of nautical charts from hydrographic surveys. Representatives of twenty-two nations formed a Hydrographic Conference in London in 1919. That conference resulted in the establishment of the **International Hydrographic Bureau (IHB)** in Monaco in 1921. Today, the IHB's successor, the **International Hydrographic Organization (IHO)** continues to provide international standards for the cartographers of its member nations. (See Chapter 1, Introduction to Marine Navigation, for a description of the IHO.)

Recognizing the considerable duplication of effort by member states, the IHO in 1967 moved to introduce the first **international chart**. It formed a committee of six member states to formulate specifications for two series of international charts. Eighty-three small-scale charts were approved; responsibility for compiling these charts has subsequently been accepted by the member states' Hydrographic Offices.

Once a Member State publishes an international chart, reproduction material is made available to any other Member State which may wish to print the chart for its own purposes.

International charts can be identified by the letters INT before the chart number and the International Hydrographic Organization seal in addition to other national seals which may appear.

CHART NUMBERING SYSTEM

344. Description Of The Numbering System

NIMA and NOS use a system in which numbers are assigned in accordance with both the scale and geographical area of coverage of a chart. With the exception of certain charts produced for military use only, one- to five-digit numbers are used. With the exception of one-digit numbers, the first digit identifies the area; the number of digits establishes the scale range. The one-digit numbers are used for certain products in the chart system which are not actually charts.

Number of Digits	*Scale*
1	No Scale
2	1:9 million and smaller
3	1:2 million to 1:9 million
4	Special Purpose
5	1:2 million and larger

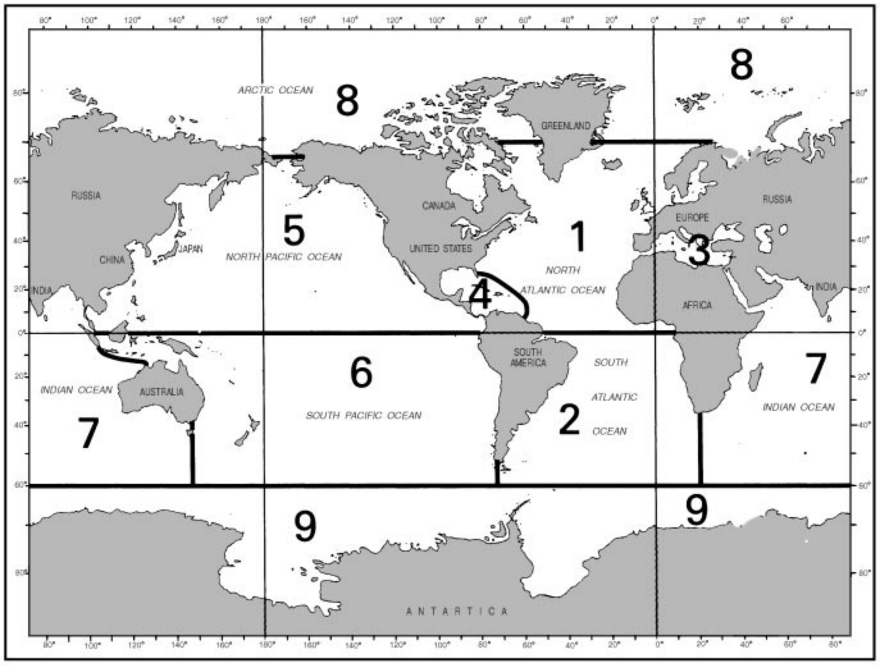


Figure 344a. Ocean basins with region numbers.

Two- and three-digit numbers are assigned to those small-scale charts which depict a major portion of an ocean basin or a large area. The first digit identifies the applicable ocean basin. See Figure 344a. Two-digit numbers are used for charts of scale 1:9,000,000 and smaller. Three-digit numbers are used for charts of scale 1:2,000,000 to 1:9,000,000.

Due to the limited sizes of certain ocean basins, no charts for navigational use at scales of 1:9,000,000 and smaller are published to cover these basins. The otherwise unused two-digit numbers (30 to 49 and 70 to 79) are assigned to special world charts such as chart 33, *Horizontal Intensity of the Earth's Magnetic Field*, chart 42, *Magnetic Variation*, and chart 76, *Standard Time Zone Chart of the World*.

One exception to the scale range criteria for three-digit numbers is the use of three-digit numbers for a series of position plotting sheets. They are of larger scale than 1:2,000,000 because they have application in ocean basins and can be used in all longitudes.

Four-digit numbers are used for non-navigational and special purpose charts, such as chart 5090, *Maneuvering Board*; chart 5101, *Gnomonic Plotting Chart North Atlantic*; and chart 7707, *Omega Plotting Chart*.

Five-digit numbers are assigned to those charts of scale 1:2,000,000 and larger that cover portions of the coastline rather than significant portions of ocean basins. These charts are based on the regions of the nautical chart index. See Figure 344b.

The first of the five digits indicates the region; the second digit indicates the subregion; the last three digits indicate the geographical sequence of the chart within the subregion. Many numbers have been left unused so that any future charts may be placed in their proper geographical sequence.

In order to establish a logical numbering system within the geographical subregions (for the 1:2,000,000 and larger-scale charts), a worldwide skeleton framework of coastal charts was laid out at a scale 1:250,000. This series was used as basic coverage except in areas where a coordinated series at about this scale already existed (such as the coast of Norway where a coordinated series of 1:200,000 charts was available). Within each region, the geographical subregions are numbered counterclockwise around the continents, and within each subregion the basic series also is numbered counterclockwise around the continents. The basic coverage is assigned generally every 20th digit, except that the first 40 numbers in each subregion are reserved for smaller-scale coverage. Charts with scales larger than the basic coverage are assigned one of the 19 numbers following the number assigned to the sheet within which it falls. Figure 344c shows the numbering sequence in Iceland. Note the sequence of numbers around the coast, the direction of numbering, and the numbering of larger scale charts within the limits of smaller scales.

Five-digit numbers are also assigned to the charts produced by other hydrographic offices. This numbering system is applied to foreign charts so that they can be filed in logical sequence with the charts produced by the National Imagery and Mapping Agency and the National Ocean Service.

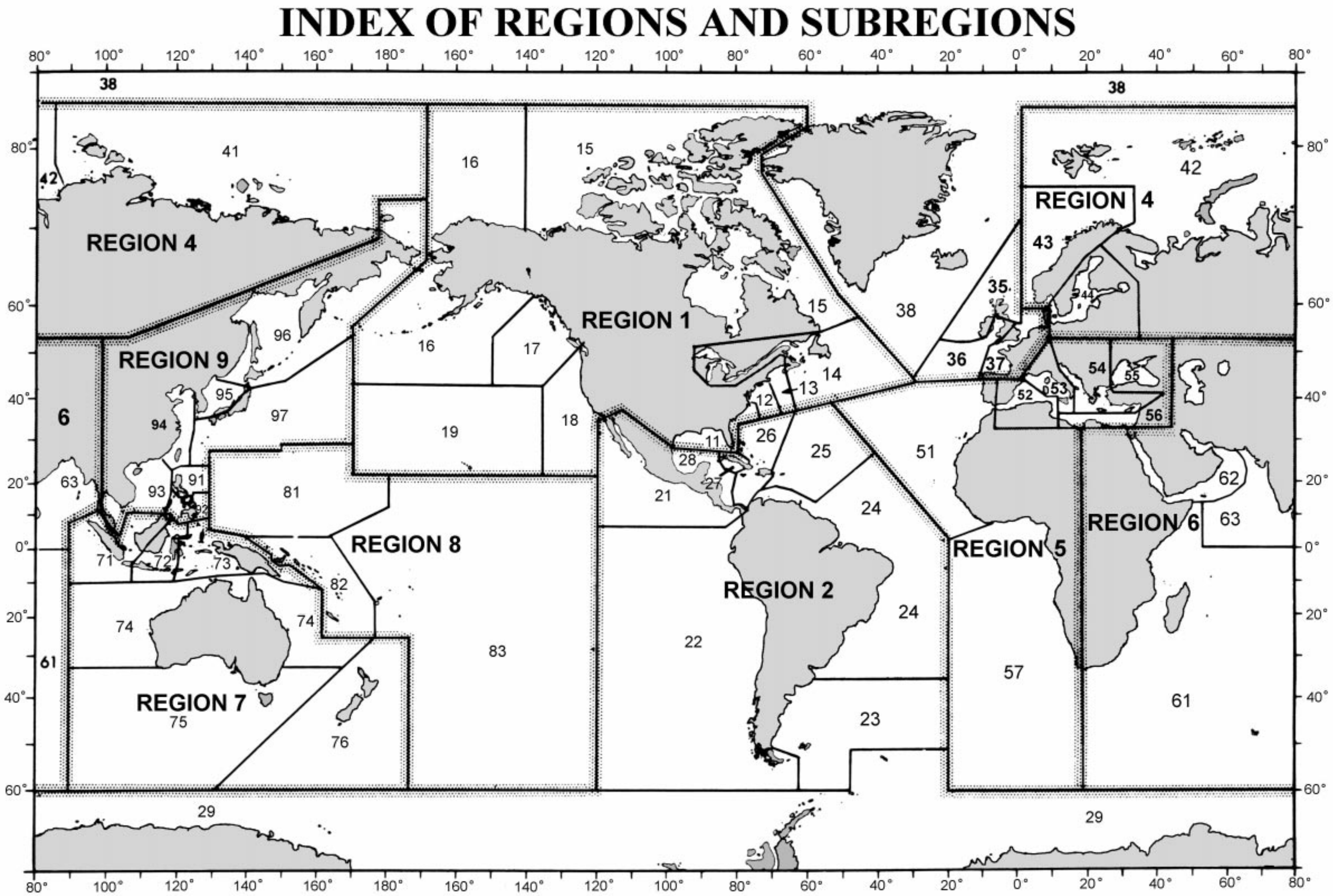


Figure 344b. Regions and subregions of the nautical chart index.

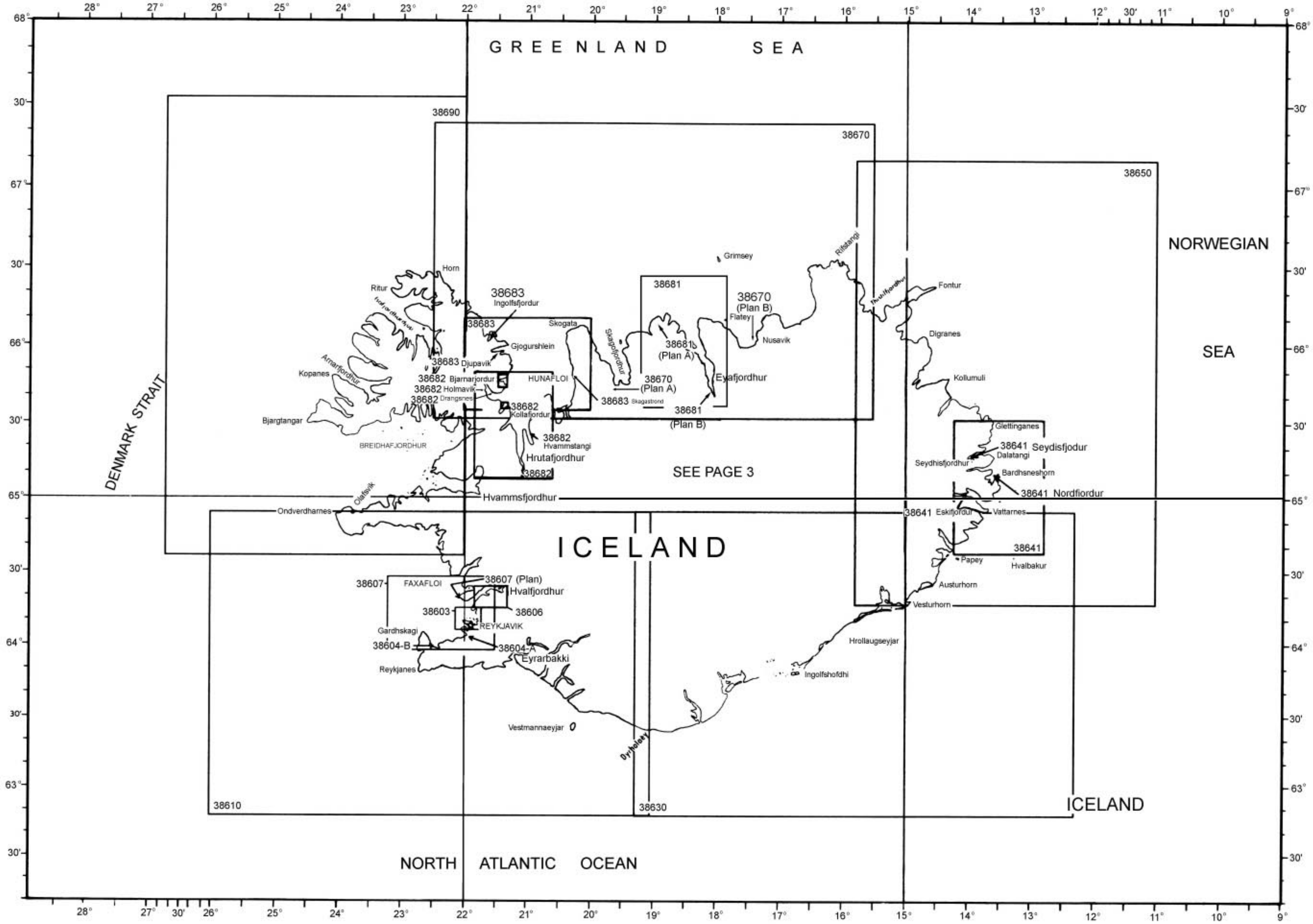


Figure 344c. Chart coverage of Iceland, illustrating the sequence and direction of the U.S. chart numbering system.

345. Exceptions To The System

Exceptions to the numbering system for military needs are as follows:

1. Bottom contour charts are not intended for surface navigation, and do not portray portions of a coastline. They chart parts of the ocean basins. They are identified with a letter plus four digits and are not available to civilian navigators.

2. Combat charts have 6-digit numbers beginning with an “8.” They are not available to civilian navigators.

346. Chart Catalogs

Chart catalogs provide information regarding not only chart coverage, but also a variety of special purpose charts and publications of interest. Keep a corrected chart catalog aboard ship for review by the navigator. The NIMA catalog is available to military navigators. It contains operating area charts and other special products not available for civilian use, but it does not contain any classified listings. The NOS catalogs contain all unclassified civilian-use NOS and NIMA charts. Military navigators receive their nautical charts and publications directly from NIMA; civilian navigators purchase them from NOS sales agents.

347. Stock Numbers

The stock number and bar code are generally found in the lower left corner of a NIMA chart, and in the lower right corner of an NOS chart. The first two digits of the stock number refer to the region and subregion. These are followed by three letters, the first of which refers to the portfolio to which the chart belongs; the second two denote the type of chart: CO for coastal, HA for harbor and approach, and OA for military operating area charts. The last five digits are the actual chart number.

USING CHARTS

348. Preliminary Steps

Upon receiving a new paper chart, verify its announcement in the Notice to Mariners and correct it with all applicable corrections. Read all the chart’s notes; there should be no question about the meanings of symbols or the units in which depths are given. Since the latitude and longitude scales differ considerably on various charts, carefully note those on the chart to be used.

Prepare piloting charts as discussed in Chapter 8 and open ocean transit charts as discussed in Chapter 25.

Place additional information on the chart as required. Arcs of circles might be drawn around navigational lights to indicate the limit of visibility at the height of eye of an observer on the bridge. Notes regarding other information from the light lists, tide tables, tidal current tables, and sailing directions might prove helpful.

The preparation of electronic charts for use is determined by the operator’s manual for the system. If the electronic chart system in use is not IMO-approved, the navigator is required to maintain a concurrent plot on paper charts.

349. Maintaining Paper Charts

A mariner navigating on an uncorrected chart is courting disaster. The chart’s print date reflects the latest Notice to Mariners used to update the chart; responsibility for maintaining it after this date lies with the user. The weekly Notice to Mariners contains information needed for maintaining charts. Radio broadcasts give advance notice of urgent corrections. Local Notice to Mariners should be consulted for inshore areas. The navigator must develop a system to keep track of chart corrections and to ensure that the chart he is using is updated with the latest correction. A convenient way of keeping this record is with a *Chart/Publication Correction Record Card* system. Using this system, the navigator does not immediately update every chart in his portfolio when he receives the Notice to Mariners. Instead, he constructs a card for every chart in his portfolio and notes the correction on this card. When the time comes to use the chart, he pulls the chart and chart’s card, and he makes the indicated corrections on the chart. This system ensures that every chart is properly corrected prior to use.

A *Summary of Corrections*, containing a cumulative listing of previously published Notice to Mariners corrections, is published annually in 5 volumes by NIMA. Thus, to fully correct a chart whose edition date is several years old, the navigator needs only the Summary of Corrections for that region and the notices from that Summary forward; he does not need to obtain notices all the way back to the edition date. See Chapter 4, Nautical Publications, for a description of the Summaries and Notice to Mariners.

When a new edition of a chart is published, it is normally furnished automatically to U.S. Government vessels. It should not be used until it is announced as ready for use in the Notice to Mariners. Until that time, corrections in the Notice apply to the old edition and should not be applied to the new one. When it is announced, a new edition of a chart replaces an older one.

Commercial users and others who don’t automatically receive new editions should obtain new editions from their sales agent. Occasionally, charts may be received or purchased several weeks in advance of their announcement in the Notice to Mariners. This is usually due to extensive rescheming of a chart region and the need to announce groups of charts together to avoid lapses in coverage. The mariner bears the responsibility for ensuring that his charts are the

current edition. The very fact that a new edition has been prepared indicates that there have been changes that cannot adequately be shown by hand corrections.

350. Use And Stowage Of Charts

Use and stow charts carefully. This is especially true with digital charts contained on electronic media. Keep optical and magnetic media containing chart data out of the sun, inside dust covers, and away from magnetic influences. Placing a disk in an inhospitable environment will destroy important data.

Make permanent corrections to paper charts in ink so that they will not be inadvertently erased. Pencil in all other markings so that they can be easily erased without damaging the chart. Lay out and label tracks on charts of frequently-traveled ports in ink. Draw lines and labels no larger than necessary. Do not obscure sounding data or other information when labeling a chart. When a voyage is completed, carefully erase the charts unless there has been a grounding or collision. In this case, preserve the charts without change because they will play a critical role in the investigation.

When not in use, stow charts flat in their proper portfolio. Minimize their folding and properly index them for easy retrieval.

351. Chart Lighting

Mariners often work in a red light environment because red light is least disturbing to night adapted vision. Such lighting seriously affects the appearance of a chart. Before using a chart in red light, test the effect red light has on its markings. Do not outline or otherwise indicate navigational hazards in red pencil because red markings disappear under red light.

The above point cannot be overemphasized; do not highlight danger areas on charts with red markers. Several ships have grounded on charted hazards simply because their conning officers were operating in a red light environment that obscured dangers highlighted on their charts in red pen. Always highlight danger areas on charts with a color that will not disappear in red light.

352. Small-Craft Charts

Although the small-craft charts published by the National Ocean Service are designed primarily for boatmen, these charts at scales of 1:80,000 and larger are in some cases the only charts available of inland waters transited by large vessels. In other cases the small-craft charts may provide a better presentation of navigational hazards than the standard nautical chart because of scale and detail. Therefore, navigators should use these charts in areas where they provide the best coverage.

CHAPTER 4

NAUTICAL PUBLICATIONS

INTRODUCTION

400. Definitions

The navigator uses many information sources when planning and conducting a voyage. These sources include notices to mariners, sailing directions, light lists, tide tables, sight reduction tables, and almanacs. Historically, this information has been found in printed publications; increasingly, it is being integrated into computer-based electronic systems. The navigator must know what information he needs to navigate his ship safely and how to obtain it.

This chapter will refer only to printed publications. If the navigator has access to this data on an electronic database, only his method of access will differ. The publications discussed here form a basic navigation library; the navigator must also obtain all supplementary materials required to navigate his ship safely.

401. Types And Sources Of Publications

While voyage planning and navigating, a mariner must refer to both texts and tables. Examples of text include sailing directions, coast pilots, and notices to mariners. Examples of tables include light lists and sight reduction tables.

Navigational publications are available from many sources. Military customers automatically receive or requisition most required publications. The civilian navigator obtains his publications from a publisher's agent. Larger agents representing many publishers can completely supply a ship's chart and publication library.

NAUTICAL TEXTS

402. Sailing Directions

National Imagery and Mapping Agency *Sailing Directions* consist of 37 **Enroutes** and 10 **Planning Guides**. Planning Guides describe general features of ocean basins; Enroutes describe features of coastlines, ports, and harbors.

Sailing Directions are updated when new data requires extensive revision of an existing text. These data are obtained from several sources, including pilots and foreign Sailing Directions.

One book comprises the Planning Guide and Enroute for Antarctica. This consolidation allows for a more effective presentation of material on this unique area.

The Planning Guides are relatively permanent; by contrast, Sailing Directions (Enroute) are frequently updated. Between updates, both are corrected by the *Notice to Mariners*.

403. Sailing Directions (Planning Guide)

Planning Guides assist the navigator in planning an extensive oceanic voyage. Each of the Guides covers an area determined by an arbitrary division of the world's seas into eight "ocean basins." This division is shown in Figure 403.

A Planning Guide's first chapter contains information about the countries adjacent to the applicable ocean basin. It also covers pratique, pilotage, signals, and shipping regulations. Search and Rescue topics include the location of all lifesaving stations.

The second chapter contains information on the physical environment of an ocean basin. It consists of Ocean Summaries and descriptions of local coastal phenomena. This gives the mariner meteorological and oceanographic information to be considered in planning a route.

The third chapter lists foreign firing danger areas not shown in other NIMA publications. A graphic key identifies Submarine Operating Areas. This chapter also identifies publications listing danger areas and gives pertinent navigation cautions.

The fourth chapter describes recommended steamship routes. To facilitate planning, the publication shows entire routes to foreign ports originating from all major U.S. ports. This chapter also includes all applicable Traffic Separation Schemes.

The fifth and final chapter describes available radionavigation systems and the area's system of lights, beacons, and buoys.

Appendices contain information on buoyage systems, route charts, and area meteorological conditions.

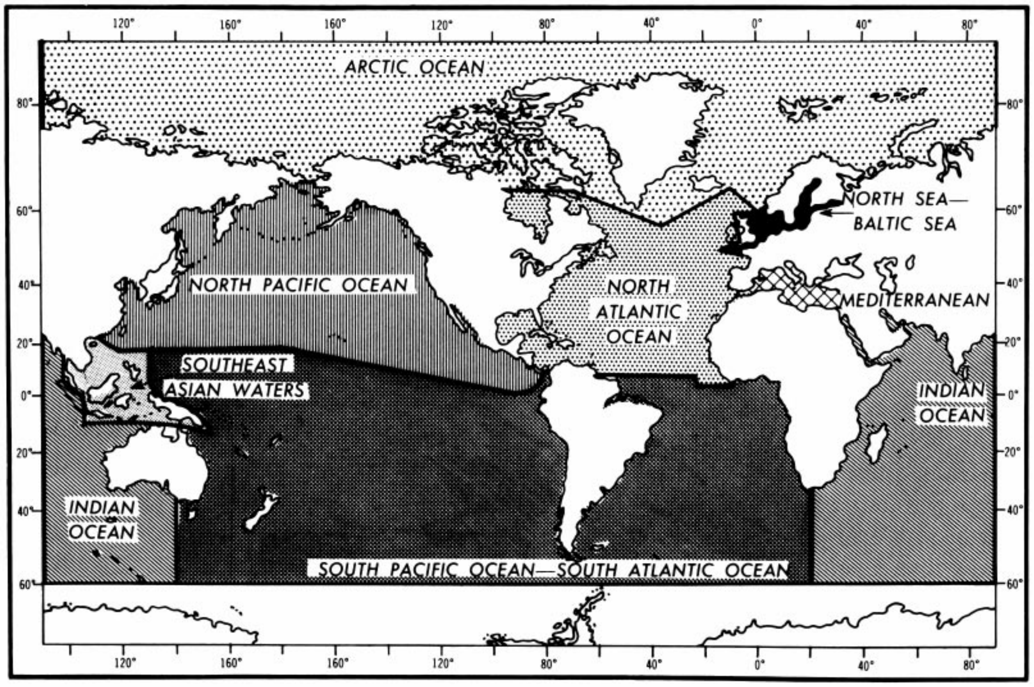


Figure 403. The 8 ocean basins as organized for Sailing Directions (Planning Guides).

404. Sailing Directions (Enroute)

Each volume of the *Sailing Directions* (Enroute) contains numbered sections along a coast or through a strait. Figure 404a illustrates this division. Each sector is discussed in turn. A preface with detailed information about authorities, references, and conventions used in each book precedes the sector discussions. Finally, each book provides conversions between feet, fathoms, and meters.

The Chart Information Graphic, the first item in each chapter, is a graphic key for charts pertaining to a sector. See Figure 404b. The graduation of the border scale of the chartlet enables navigators to identify the largest scale chart for a location and to find a feature listed in the Index-Gazetteer. These graphics are not maintained by *Notice to Mariners*; one should refer to the chart catalog for updated chart listings.

Other graphics may contain special information on local winds and weather, anchorages, significant coastal features, and navigation dangers.

A foreign terms glossary, an appendix of anchorages, and a comprehensive Index-Gazetteer follow the sector discussions. The Index-Gazetteer is an alphabetical listing of described and charted features. The Index lists each feature by geographic coordinates and sector number for use with the graphic key. Features mentioned in the text are listed by page number.

405. Coast Pilots

The National Ocean Service publishes nine *United States Coast Pilots* to supplement nautical charts of U.S. waters. Information comes from field inspections, survey vessels, and various harbor authorities. Maritime officials and pilotage associations provide additional information. *Coast Pilots* provide more detailed information than Sailing Directions because Sailing Directions are intended exclusively for the oceangoing mariner. The *Notice to Mariners* updates *Coast Pilots*.

Each volume contains comprehensive sections on local operational considerations and navigation regulations. Following chapters contain detailed discussions of coastal navigation. An appendix provides information on obtaining additional weather information, communications services, and other data. An index and additional tables complete the volume.

406. Other Nautical Texts

The government publishes several other nautical texts. The Defense Mapping Agency, for example, publishes the *Maneuvering Board Manual* (*Pub. 217*), *The Radar Navigation Manual* (*Pub.1310*) and the *American Practical Navigator* (*Pub. 9*).

The U.S. Coast Guard publishes navigation rules for international and inland waters. This publication, officially known as Commandant Instruction M16672.2b, contains

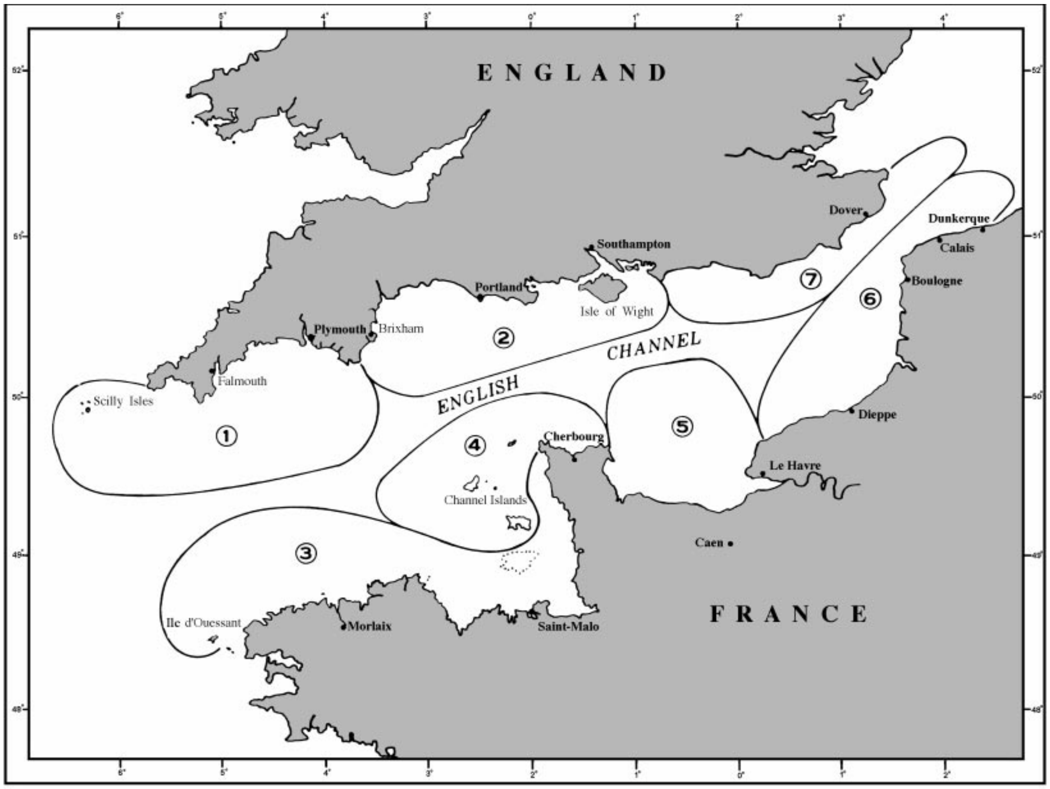
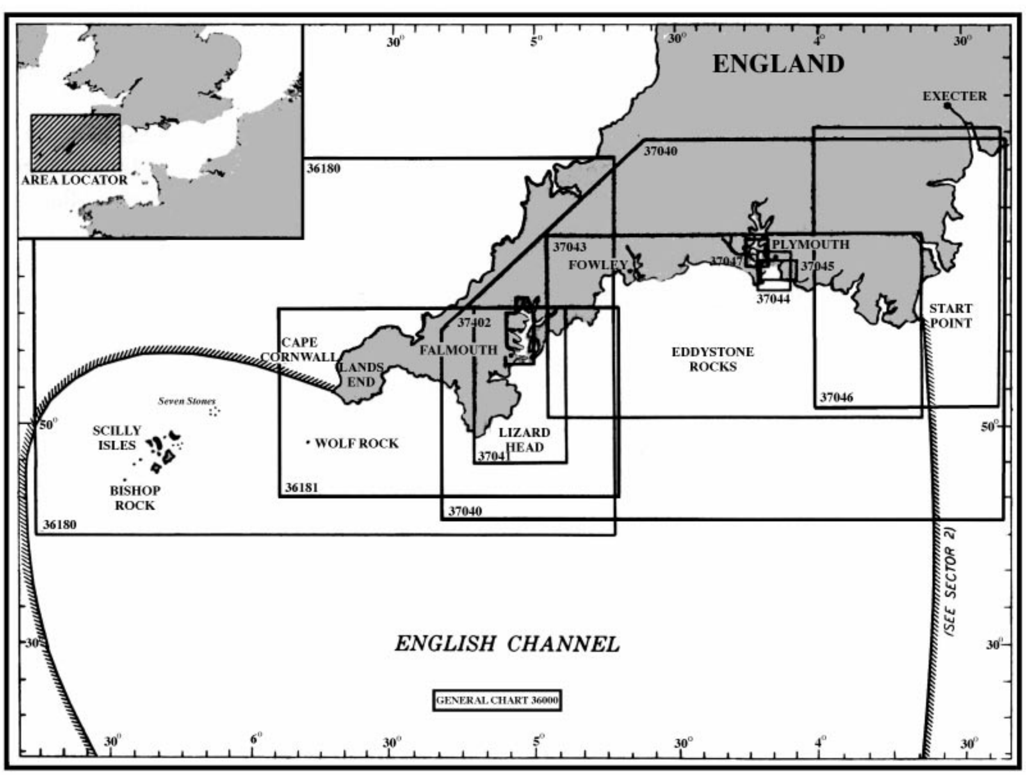


Figure 404a. Sector Limits graphic.



Additional chart coverage may be found in CATP2 Catalog of Nautical Charts.

Figure 404b. Chart Information graphic.

the Inland Navigation Rules enacted in December 1980 and effective on all inland waters of the United States including the Great Lakes, as well as the International Regulations for the Prevention of Collisions at Sea, enacted in 1972 (1972 COLREGS). Mariners should ensure that they have the updated issue. The Coast Guard also publishes comprehensive user's manuals for the Omega, Loran, and GPS navigation systems; *Navigation and Vessel Inspection Circulars*; and the *Chemical Data Guide for Bulk Shipment by Water*.

The Government Printing Office provides several publications on navigation, safety at sea, communications, weather, and related topics. Additionally, it publishes provisions of the Code of Federal Regulations (CFR) relating to maritime matters. A number of private publishers also provide maritime publications.

The International Maritime Organization, International Hydrographic Organization, and other governing international organizations provide information on international navigation regulations. Chapter 1 gives these organizations' addresses. Regulations for various Vessel Traffic Services (VTS), canals, lock systems, and other regulated waterways are published by the authorities which operate them.

USING THE LIGHT LISTS

407. Light Lists

The United States publishes two different light lists. The U.S. Coast Guard publishes the *Light List* for lights in U.S. territorial waters; DMAHTC publishes the *List of Lights* for lights in foreign waters.

Light lists furnish complete information about navigation lights and other navigation aids. They supplement, but do not replace, charts and sailing directions. Consult the chart for the location and light characteristics of all navigation aids; consult the light lists to determine their detailed description.

The *Notice to Mariners* corrects both lists. Corrections which have accumulated since the print date are included in the *Notice to Mariners* as a *Summary of Corrections.* All of these summary corrections, and any corrections published subsequently, should be noted in the "Record of Corrections."

A navigator needs to know both the identity of a light and when he can expect to see it; he often plans the ship's track to pass within a light's range. If lights are not sighted when predicted, the vessel may be significantly off course and standing into danger.

A circle with a radius equal to the visible range of the light usually defines the area in which a light can be seen. On some bearings, however, obstructions may reduce the range. In this case, the obstructed arc might differ with height of eye and distance. Also, lights of different colors may be seen at different distances. Consider these facts both when identifying a light and predicting the range at which it can be seen.

Atmospheric conditions have a major effect on a light's range. Fog, haze, dust, smoke, or precipitation can obscure a light. Additionally, a light can be extinguished. Always report an extinguished light so maritime authorities can issue a warning.

On a dark, clear night, the visual range is limited by either: (1) luminous intensity, or (2) curvature of the earth. Regardless of the height of eye, one cannot see a weak light beyond a certain luminous range. Assuming light travels linearly, an observer located below the light's visible horizon cannot see it. The Distance to the Horizon table gives the distance to the horizon for various heights of eye. The light lists contain a condensed version of this table. Abnormal refraction patterns might change this range; therefore, one cannot exactly predict the range at which a light will be seen.

408. Determining Range And Bearing Of A Light At Initial Sighting

A light's **luminous range** is the maximum range at which an observer can see a light under existing visibility conditions. This luminous range ignores the elevation of the light, the observer's height of eye, the curvature of the earth, and interference from background lighting. It is determined from the known **nominal range** and the existing visibility conditions. The nominal range is the maximum distance at which a light can be seen in weather conditions where visibility is 10 nautical miles.

The U.S. Coast Guard Light List usually lists a light's nominal range. Use the Luminous Range Diagram shown in the Light List and Figure 408a to convert this nominal range to luminous range. Remember that the luminous ranges obtained are approximate because of atmospheric or background lighting conditions. Estimate the meteorological visibility by the Meteorological Optical Range Table, Figure 408b. Next, enter the Luminous Range Diagram with the nominal range on the horizontal nominal range scale. Follow a vertical line until it intersects the curve or reaches the region on the diagram representing the meteorological visibility. Finally, follow a horizontal line from this point or region until it intersects the vertical luminous range scale.

Example 1: *The nominal range of a light as extracted from the Light List is 15 nautical miles.*

Required: *The luminous range when the meteorological visibility is (1) 11 nautical miles and (2) 1 nautical mile.*

Solution: *To find the luminous range when the meteo-*

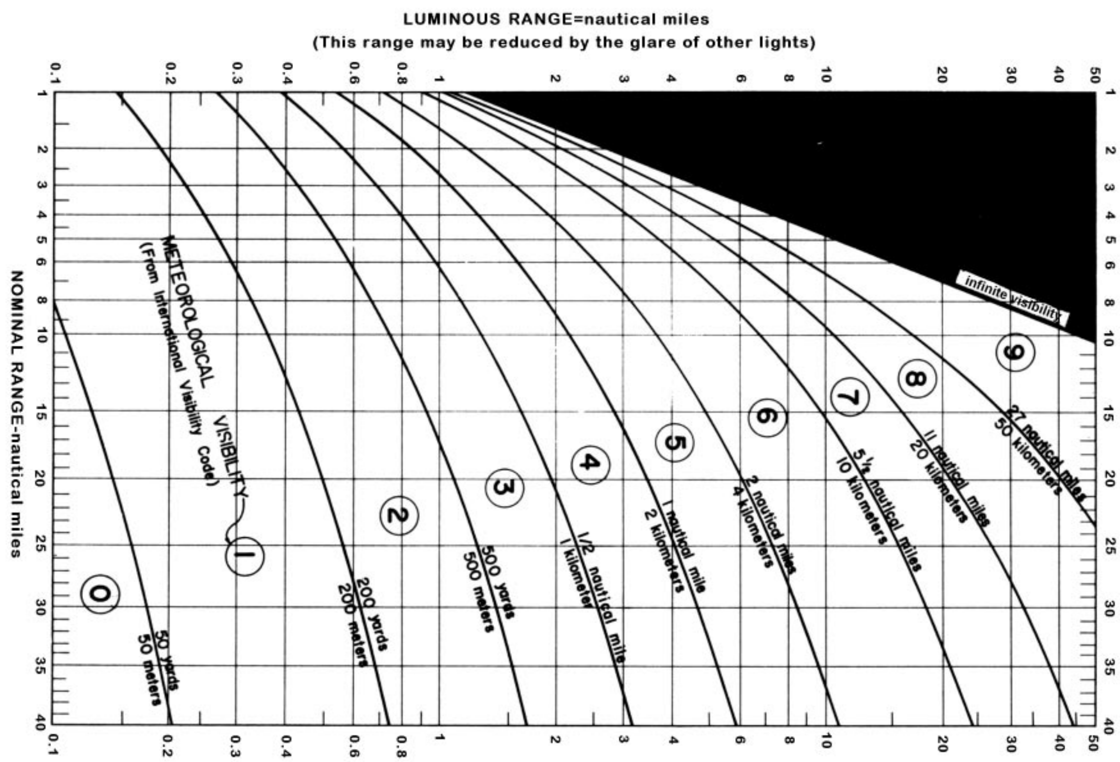


Figure 408a. Luminous Range Diagram.

rological visibility is 11 nautical miles, enter the Luminous Range Diagram with nominal range 15 nautical miles on the horizontal nominal range scale; follow a vertical line upward until it intersects the curve on the diagram representing a meteorological visibility of 11 nautical miles; from this point follow a horizontal line to the right until it intersects the vertical luminous range scale at 16 nautical miles. A similar procedure is followed to find the luminous range when the meteorological visibility is 1 nautical mile.

Answers: *(1) 16 nautical miles; (2) 3 nautical miles.*

A light's **geographic range** depends upon the height of both the light and the observer. Sum the observer's distance to the horizon based on his height of eye and the light's distance to the horizon based on its height to calculate a light's geographic range. See Figure 408c. This illustration uses a light 150 feet above the water. Table 12, Distance of the Horizon, yields a value of 14.3 nautical miles for a height of 150 feet. Within this range, the light, if powerful enough and atmospheric conditions permit, is visible regardless of the height of eye of the observer. Beyond 14.3 nautical miles, the geographic range depends upon the observer's height of eye. Thus, by the Distance of the Horizon table mentioned above, an observer with height of eye of 5 feet can see the light on his horizon if he is 2.6 miles beyond the horizon of the light. The geographic range of the light is therefore 16.9 miles. For a height of 30 feet the distance is 14.3 + 6.4 = 20.7 miles. If the height of eye is 70 feet, the geographic range is 14.3 + 9.8 = 24.1 miles. A height of eye of 15 feet is often assumed when tabulating lights' geographic ranges.

Code No.	Weather	Yards
0	Dense fog	Less than 50
1	Thick fog	50-200
2	Moderate fog	200-500
3	Light fog	500-1000
		Nautical Miles
4	Thin fog	1/2-1
5	Haze	1-2
6	Light Haze	2-5 1/2
7	Clear	5 1/2-11
8	Very Clear	11.0-27.0.
9	Exceptionally Clear	Over 27.0

From the International Visibility Code.

Figure 408b. Meteorlogical Optical Range Table.

To predict the bearing and range at which a vessel will initially sight a light first determine the light's geographic range. Compare the geographic range with the light's luminous range. The lesser of the two ranges is the range at which the light will first be sighted. Plot a visibility arc centered on the light and with a radius equal to the lesser of the geographic or luminous ranges. Extend the vessel's track until it intersects the visibility arc. The bearing from the intersection point to the light is the light's predicted bearing at first sighting.

If the extended track crosses the visibility arc at a small angle, a small lateral track error may result in large bearing and time prediction errors. This is particularly apparent if the vessel is farther from the light than predicted; the vessel may pass the light without sighting it. However, not sighting a light when predicted does not always indicate the vessel is farther from the light than expected. It could also mean that atmospheric conditions are affecting visibility.

Example 2: *The nominal range of a navigational light 120 feet above the chart datum is 20 nautical miles. The meteorological visibility is 27 nautical miles.*

Required: *The distance at which an observer at a height of eye of 50 feet can expect to see the light.*

Solution: *The maximum range at which the light may be seen is the lesser of the luminous or geographic ranges. At 120 feet the distance to the horizon, by table or formula, is 12.8 miles. Add 8.3 miles, the distance to the horizon for a height of eye of 50 feet to determine the geographic range. The geographic range, 21.1 miles, is less than the luminous range, 40 miles.*

Answer: *21 nautical miles. Because of various uncertainties, the range is rounded off to the nearest whole mile.*

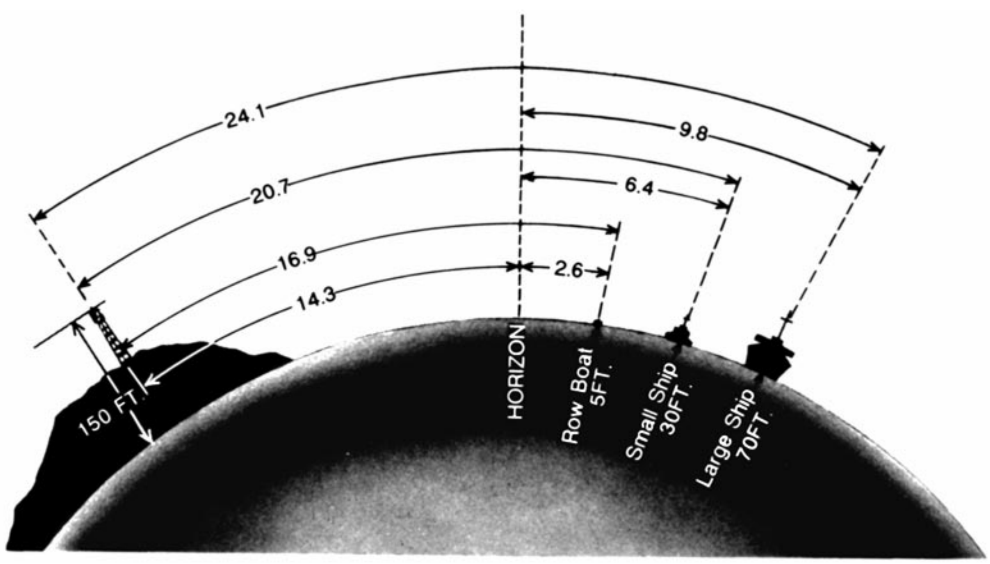


Figure 408c. Geographic Range of a light.

When first sighting a light, an observer can determine if it is on the horizon by immediately reducing his height of eye. If the light disappears and then reappears when the observer returns to his original height, the light is on the horizon. This process is called **bobbing a light**.

If a vessel has considerable vertical motion due to rough seas, a light sighted on the horizon may alternately appear and disappear. Wave tops may also obstruct the light periodically. This may cause the characteristic to appear different than expected. The light's true characteristics can be observed either by closing the range to the light or by the observer's increasing his height of eye.

If a light's range given in a foreign publication approximates the light's geographic range for a 15-foot observer's height of eye, assume that the printed range is the light's geographic range. Also assume that publication has listed the lesser of the geographic and nominal ranges. Therefore, if the light's listed range approximates the geographic range for an observer with a height of eye of 15 feet, then assume that the light's limiting range is the geographic range. Then, calculate the light's true geographic range using the actual observer's height of eye, not the assumed height of eye of 15 feet. This calculated true geographic range is the range at which the light will first be sighted.

Example 3: *The range of a light as printed on a foreign chart is 17 miles. The light is 120 feet above chart datum. The meteorological visibility is 10 nautical miles.*

Required: *The distance at which an observer at a height of eye of 50 feet can expect to see the light.*

Solution: *Calculate the geographic range of the light assuming a 15 foot observer's height of eye. At 120 feet the distance to the horizon is 12.8 miles. Add 4.5 miles (the distance to the horizon at a height of 15 feet) to 12.8 miles; this range is 17.3 miles. This approximates the range listed on the chart. Then assuming that the charted range is the geographic range for a 15-foot observer height of eye and that the nominal range is the greater than this charted range, the predicted range is found by calculating the true geographic range with a 50 foot height of eye for the observer.*

Answer: *The predicted range = 12.8 mi. + 8.3 mi. = 21.1 mi.. The distance in excess of the charted range depends on the luminous intensity of the light and the meteorological visibility.*

409. USCG *Light Lists*

The U.S. Coast Guard *Light List* (7 volumes) gives information on lighted navigation aids, unlighted buoys, radiobeacons, radio direction finder calibration stations, daybeacons, racons, and Loran stations.

Each volume of the *Light List* contains aids to navigation in geographic order from north to south along the Atlantic coast, from east to west along the Gulf coast, and from south to north along the Pacific coast. It lists seacoast aids first, followed by entrance and harbor aids listed from seaward. Intracoastal Waterway aids are listed last in geographic order in the direction from New Jersey to Florida to the Texas/Mexico border.

The listings are preceded by a description of the aids to navigation system in the United States, luminous range diagram, geographic range tables, and other information.

410. NIMA *List of Lights, Radio Aids, and Fog Signals*

The National Imagery and Mapping Agency publishes the *List of Lights, Radio Aids, and Fog Signals* (usually referred to as the *List of Lights,* not to be confused with the Coast Guard's *Light List*). In addition to information on lighted aids to navigation and sound signals in foreign waters, the NIMA *List of Lights* provides information on storm signals, signal stations, racons, radiobeacons, and radio direction finder calibration stations located at or near lights. For more details on radio navigational aids, consult *Pub. 117, Radio Navigational Aids.*

The NIMA *List of Lights* does not include information on lighted buoys inside harbors. It does include certain aeronautical lights situated near the coast; however, these lights are not designed for marine navigation and are subject to unreported changes.

Foreign notices to mariners are the main correctional information source for the NIMA *Lists of Lights*; other sources, such as ship reports, are also used. Many aids to navigation in less developed countries may not be well maintained. They are subject to damage by storms and vandalism, and repairs may be delayed for long periods.

MISCELLANEOUS NAUTICAL PUBLICATIONS

411. NIMA *Radio Navigational Aids (Pub. 117)*

This publication is a selected list of worldwide radio stations which perform services to the mariner. Topics covered include radio direction finder and radar stations, radio time signals, radio navigation warnings, distress and safety communications, medical advice via radio, long-range navigation aids, the AMVER system, and interim procedures for U.S. vessels in the event of an outbreak of hostilities. *Pub. 117* is corrected via the *Notice to Mariners* and is updated periodically with a new edition.

Though *Pub. 117* is essentially a list of radio stations providing vital maritime communication and navigation services, it also contains information which explains the capabilities and limitations of the various systems.

412. *Chart No. 1*

Chart No. 1 is not actually a chart but a book containing a key to chart symbols. Most countries which produce charts also produce such a list. The U.S. *Chart No. 1* contains a listing of chart symbols in four categories:

- Chart symbols used by the National Ocean Service
- Chart symbols used by the Defense Mapping Agency
- Chart symbols recommended by the International Hydrographic Organization
- Chart symbols used on foreign charts reproduced by NIMA

Subjects covered include general features of charts, topography, hydrography, and aids to navigation. There is also a complete index of abbreviations and an explanation of the IALA buoyage system.

413. NIMA *World Port Index (Pub. 150)*

The *World Port Index* contains a tabular listing of thousands of ports throughout the world, describing their locations, characteristics, facilities, and services available. Information is arranged geographically; the index is arranged alphabetically.

Coded information is presented in columns and rows. This information supplements information in the *Sailing Directions*. The applicable volume of *Sailing Directions* and the number of the harbor chart are given in the *World Port Index*. The *Notice to Mariners* corrects this book.

414. NIMA *Distances Between Ports (Pub. 151)*

This publication lists the distances between major ports. Reciprocal distances between two ports may differ due to different routes chosen because of currents and climatic conditions. To reduce the number of listings needed, junction points along major routes are used to consolidate routes converging from different directions.

This book can be most effectively used for voyage planning in conjunction with the proper volume(s) of the *Sailing Directions (Planning Guide)*. It is corrected via the *Notice to Mariners*.

415. NIMA *International Code Of Signals (Pub. 102)*

This book lists the signals to be employed by vessels at sea to communicate a variety of information relating to safety, distress, medical, and operational information. This publication became effective in 1969.

According to this code, each signal has a unique and complete meaning. The signals can be transmitted via Morse light and sound, flag, radio-telegraphy and -telephony, and semaphore. Since these methods of signaling are internationally recognized, differences in language between sender and receiver are immaterial; the message will be understood when decoded in the language of the receiver, regardless of the language of the sender. The *Notice to Mariners* corrects *Pub. 102*.

416. Almanacs

For celestial sight reduction, the navigator needs an **almanac** for ephemeris data. The *Nautical Almanac*, produced jointly by H.M. Nautical Almanac Office and the U.S. Naval Observatory, is the most common almanac used for celestial navigation. It also contains information on sunrise, sunset, moonrise, and moonset, as well as compact sight reduction tables. The *Nautical Almanac* is published annually.

The *Air Almanac* contains slightly less accurate ephemeris data for air navigation. It can be used for marine navigation if slightly reduced accuracy is acceptable.

Chapter 19 provides more detailed information on using the *Nautical Almanac*.

417. Sight Reduction Tables

Without a calculator or computer programmed for sight reduction, the navigator needs **sight reduction tables** to solve the celestial triangle. Two different sets of tables are commonly used at sea.

Sight Reduction Tables for Marine Navigation, Pub. 229, consists of six volumes of tables designed for use with the *Nautical Almanac* for solution of the celestial triangle by the **Marcq Saint Hilaire** or **intercept** method. The tabular data are the solutions of the navigational triangle of which two sides and the included angle are known and it is necessary to find the third side and adjacent angle.

Each volume of Pub. 229 includes two 8 degree zones, comprising 15 degree bands from 0 to 90 degrees, with a 1° degree overlap between volumes. Pub. 229 is a joint publication produced by the National Imagery and Mapping Agency, the U.S. Naval Observatory, and the Royal Greenwich Observatory.

Sight Reduction Tables for Air Navigation, Pub. 249, is also a joint production of the three organizations above. It is issued in three volumes. Volume 1 contains the values of the altitude and true azimuth of seven selected stars chosen to

provide, for any given position and time, the best observations. A new edition is issued every 5 years for the upcoming astronomical epoch. Volumes 2 (0° to 40°) and 3 (39° to 89°) provide for sights of the sun, moon, and planets.

418. Catalogs

A chart catalog is a valuable reference to the navigator for voyage planning, inventory control, and ordering. There are two major types of catalogs, one for the military and one for the civilian market.

The military navigator will see the NIMA nautical chart catalog as part of a larger suite of catalogs including aeronautical (Part 1), hydrographic (Part 2), and topographic (Part 3) products. Each Part consists of one or more volumes. Unclassified NIMA nautical charts are listed in Part 2, Volume 1. This is available only to U.S. military users, DoD contractors, and those who support them.

This catalog contains comprehensive ordering instructions and information about the products listed. Also listed are addresses of all Combat Support Center field offices, information on crisis support, and other special situations. The catalog is organized by geographic region corresponding to the chart regions 1 through 9. A special section of miscellaneous charts and publications is included. This section also lists products produced by NOS, the U.S. Army Corps of Engineers, U.S. Coast Guard, U.S. Naval Oceanographic Office, and some foreign publications from the United Kingdom and Canada.

The civilian navigator should refer to catalogs produced by the National Ocean Service. For U.S. waters, NOS charts are listed in a series of single sheet “charts” showing a major region of the U.S. with individual chart graphics shown. These catalogs also list charts showing titles and scales. Finally, it lists sales agents from whom the products may be purchased.

NIMA products for the civilian navigator are listed by NOS in a series of regionalized catalogs similar to Part 2 Volume 1. These catalogs are also available through authorized NOS chart agents.

MARITIME SAFETY INFORMATION

419. *Notice To Mariners*

The ***Notice to Mariners*** is published weekly by the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC), prepared jointly with the National Ocean Service (NOS) and the U.S. Coast Guard. It advises mariners of important matters affecting navigational safety, including new hydrographic information, changes in channels and aids to navigation, and other important data. The information in the *Notice to Mariners* is formatted to simplify the correction of paper charts, sailing directions, light lists, and other publications produced by NIMA, NOS, and the U.S. Coast Guard.

It is the responsibility of users to decide which of their charts and publications require correction. Suitable records of *Notice to Mariners* should be maintained to facilitate the updating of charts and publications prior to use.

Information for the *Notice to Mariners* is contributed by: the Defense Mapping Agency Hydrographic/Topographic Center (Department of Defense) for waters outside the territorial limits of the United States; National Ocean Service (National Oceanic and Atmospheric Administration, Department of Commerce), which is charged with surveying and charting the coasts and harbors of the United States and its territories; the U.S. Coast Guard (Department of Transportation) which is responsible for the safety of life at sea and the establishment and operation of aids to navigation; and the Army Corps of Engineers (Department of Defense), which is charged with the improvement of rivers and harbors of the United States. In addition, important contributions are made by foreign hydrographic offices and cooperating observers of all nationalities.

Over 60 countries which produce nautical charts also produce a notice to mariners. About one third of these are weekly, another third are bi-monthly or monthly, and the rest irregularly issued according to need. Much of the data in the U.S. *Notice to Mariners* is obtained from these foreign notices.

Correct U.S. charts with the U.S. *Notice to Mariners*. Similarly, correct foreign charts using the foreign notice because chart datums often vary according to region and geographic positions are not the same for different datums.

The *Notice* consists of a page of **Hydrograms** listing important items in the notice, a chart correction section organized by ascending chart number, a publications correction section, and a summary of broadcast navigation warnings and miscellaneous information.

Mariners are requested to cooperate in the correction of charts and publications by reporting all discrepancies between published information and conditions actually observed and by recommending appropriate improvements. A convenient reporting form is provided in the back of each *Notice to Mariners*.

Notice to Mariners No. 1 of each year contains important information on a variety of subjects which supplements information not usually found on charts and in navigational publications. This information is published as **Special Notice to Mariners Paragraphs**. Additional items considered

of interest to the mariner are also included in this *Notice*.

420. *Summary Of Corrections*

A close companion to the *Notice to Mariners* is the ***Summary of Corrections***. The *Summary* is published in five volumes. Each volume covers a major portion of the earth including several chart regions and many subregions. Volume 5 also includes special charts and publications corrected by the *Notice to Mariners*. Since the *Summaries* contain cumulative corrections, any chart, regardless of its print date, can be corrected with the proper volume of the *Summary* and all subsequent *Notice to Mariners*.

421. The Navigation Information Network

Most of the weekly *Notice to Mariners* production is computerized. This system is known as the **Automated Notice to Mariners System (ANMS)**. Design work on this system began in 1975, and the first *Notice* produced with it was issued in 1980. This system's software allows remote query via modem. This remote access system is known as the **Navigation Information Network (NAVINFONET)**.

Data available through NAVINFONET includes chart corrections,NIMA *List of Lights* corrections, Coast Guard *Light List* corrections, radio warnings, MARAD Advisories, NIMA hydrographic product catalog corrections, drill rig locations, ship hostile action report (SHAR) files, and GPS navigation system status reports. Messages can also be left for NIMA staff regarding suggestions, changes, corrections or comments on any navigation products.

The system does not have the capability to send graphics files, which prevents the transfer of chartlets. However, navigators can access most other significant information contained in the *Notice to Mariners*. Information is updated daily or weekly according to the *Notice to Mariners* production schedule. The system supports most internationally recognized telephone protocols and can presently transfer data at a maximum rate of 9600 baud.

NAVINFONET is not a replacement for the weekly *Notice to Mariners*, and in certain respects the accuracy of information cannot be verified by DMA. Certain files, for example, are entered directly into the data base without editing by NIMA staff. Also, drill rig locations are furnished by the companies which operate them. They are not required to provide these positions, and they cannot be verified. However, within these limitations, the system can provide information 2 to 3 weeks sooner than the printed *Notice to Mariners*, because the paper *Notice* must be compiled, edited, printed, and mailed after the digital version is completed.

NAVINFONET access is free, but the user must pay telephone charges. All users must register and receive a password by writing or calling NIMA, Attn.: MCC-NAVINFONET, Mail Stop D-44, 4600 Sangamore Rd., Bethesda, MD, 20816-5003; telephone (301) 227-3296.

The U.S. Coast and Geodetic Survey operates a similar free computerized marine information bulletin board containing a list of wrecks and obstructions, a nautical chart locator, a list of marine sediments samples, a datum conversion program for NAD 27 to NAD 83 datum conversions, and a list of aerial photographs available from NOAA. The modem phone number is (301) 713-4573, the voice line (301) 713-2653, and FAX (301) 713-4581. The address of the office is NOAA, NOS, C&GS, (N/CG211), 1315 East-West Highway, Silver Spring, MD, 20910

422. *Local Notice To Mariners*

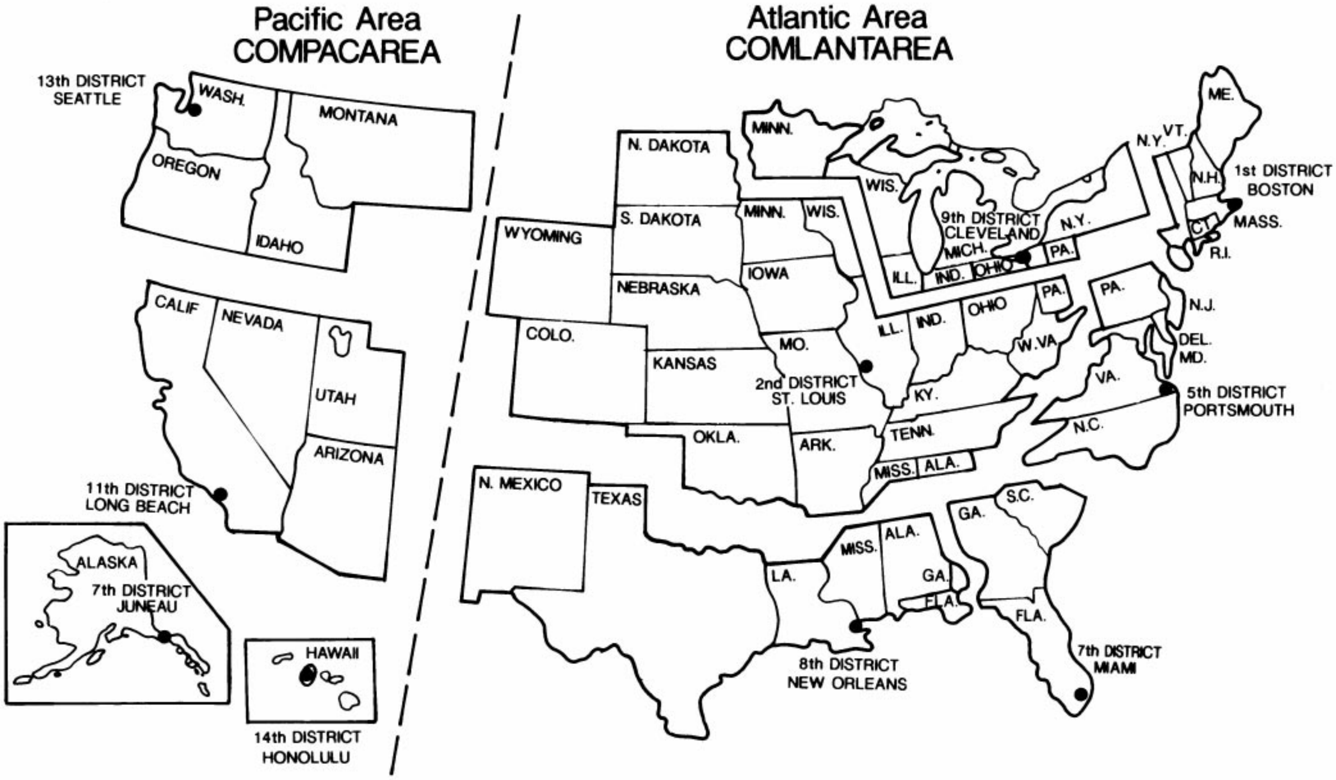
The ***Local Notice to Mariners*** is issued by each U.S. Coast Guard District to disseminate important information affecting navigational safety within that District. This *Notice* reports changes and deficiencies in aids to navigation maintained by the Coast Guard. Other marine information such as new charts, channel depths, naval operations, and regattas is included. Since temporary information of short duration is not included in the weekly *Notice to Mariners*, the *Local Notice to Mariners* may be the only source of such information. Small craft using the Intracoastal Waterway and small harbors not normally used by oceangoing vessels need it to keep charts and publications up-to-date. Since correcting information for U.S. charts in the NIMA *Notice* is obtained from the Coast Guard *Local Notices*, it is normal to expect a lag of 1 or 2 weeks for the NIMA *Notice* to publish a correction from this source.

The *Local Notice to Mariners* may be obtained free of charge by contacting the appropriate Coast Guard District Commander. Vessels operating in ports and waterways in several districts must obtain the *Local Notice to Mariners* from each district. See Figure 422 for a complete list of U.S. Coast Guard Districts.

423. Electronic Notice To Mariners

Electronic chart development is proceeding rapidly. The correction of these charts will become a major issue. In the near future, the quality standards of digital charts will permit the replacement of traditional paper charts. Neither paper nor electronic charts should be used unless corrected through the latest *Notice to Mariners*. Chapter 14 discusses potential methods for correcting electronic charts.

Until the electronic chart is recognized as being the legal equivalent of the paper chart, however, it cannot replace the paper chart on the bridge. Presently, therefore, the mariner must continue to use traditional paper charts. Their use, in turn, necessitates the continued use of the *Notice to Mariners* correction system.



COMMANDER, FIRST COAST GUARD DISTRICT
408 ATLANTIC AVENUE
BOSTON, MA 02110-3350
PHONE: DAY 617-223-8338, NIGHT 617-223-8558

COMMANDER, SECOND COAST GUARD DISTRICT
1222 SPRUCE STREET
ST. LOUIS, MO 63103-2832
PHONE: DAY 314-539-3714, NIGHT 314-539-3709

COMMANDER, FIFTH COAST GUARD DISTRICT
FEDERAL BUILDING
431 CRAWFORD STREET
PORTSMOUTH, VA 23704-5004
PHONE: DAY 804-398-6486, NIGHT 804-398-6231

COMMANDER, SEVENTH COAST GUARD DISTRICT
BRICKELL PLAZA FEDERAL BUILDING
909 SE 1ST AVENUE, RM: 406
MIAMI, FL 33131-3050
PHONE: DAY 305-536-5621, NIGHT 305-536-5611

COMMANDER GREATER ANTILLES SECTION
U.S. COAST GUARD
P.O. BOX S-2029
SAN JUAN, PR 00903-2029
PHONE: 809-729-6870

COMMANDER, EIGHTH COAST GUARD DISTRICT
HALE BOGGS FEDERAL BUILDING
501 MAGAZINE STREET
NEW ORLEANS, LA 70130-3396
PHONE: DAY 504-589-6234, NIGHT 504-589-6225

COMMANDER, NINTH COAST GUARD DISTRICT
1240 EAST 9TH STREET
CLEVELAND, OH 44199-2060
PHONE: DAY 216-522-3991, NIGHT 216-522-3984

COMMANDER, ELEVENTH COAST GUARD DISTRICT
FEDERAL BUILDING
501 W. OCEAN BLVD.
LONG BEACH, CA 90822-5399
PHONE: DAY 310-980-4300, NIGHT 310-980-4400

COMMANDER, THIRTEENTH COAST GUARD DISTRICT
FEDERAL BUILDING
915 SECOND AVENUE
SEATTLE, WA 98174-1067
PHONE: DAY 206-220-7280, NIGHT 206-220-7004

COMMANDER, FOURTEENTH COAST GUARD DISTRICT
PRINCE KALANIANAOLE FEDERAL BLDG.
9TH FLOOR, ROOM 9139
300 ALA MOANA BLVD.
HONOLULU, HI 96850-4982
PHONE: DAY 808-541-2317, NIGHT 808-541-2500

COMMANDER, SEVENTEENTH COAST GUARD DISTRICT
P.O. BOX 25517
JUNEAU, AK 99802-5517
PHONE: DAY 907-463-2245, NIGHT 907-463-2000

Figure 422. U.S. Coast Guard Districts.

CHAPTER 5

SHORT RANGE AIDS TO NAVIGATION

DEFINING SHORT RANGE AIDS TO NAVIGATION

500. Terms And Definitions

The term “short range aids to navigation” encompasses lighted and unlighted beacons, ranges, leading lights, buoys, and their associated sound signals. Each short range aid to navigation, commonly referred to as a NAVAID, fits within a system designed to warn the mariner of dangers and direct him toward safe water. An aid’s function determines its color, shape, light characteristic, and sound. This chapter explains the U.S. Aids to Navigation System as well as the international IALA Maritime Buoyage System.

The placement and maintenance of marine aids to navigation in U.S. waters is the responsibility of the United States Coast Guard. The Coast Guard maintains lighthouses, radiobeacons, racons, Loran C, sound signals, buoys, and daybeacons on the navigable waters of the United States, its territories, and possessions. Additionally, the Coast Guard exercises control over privately owned navigation aid systems.

A **beacon** is a stationary, visual navigation aid. Large lighthouses and small single-pile structures are both beacons. Lighted beacons are called **lights**; unlighted beacons are **daybeacons**. All beacons exhibit a **daymark** of some sort. In the case of a lighthouse, the color and type of structure are the daymarks. On small structures, these daymarks, consisting of colored geometric shapes called **dayboards**, often have lateral significance. Conversely, the markings on lighthouses and towers convey no lateral significance.

FIXED LIGHTS

501. Major And Minor Lights

Lights vary from tall, high intensity coastal lights to battery-powered lanterns on single wooden piles. Immovable, highly visible, and accurately charted, fixed lights provide navigators with an excellent source for bearings. The structures are often distinctively colored to aid in identification. See Figure 501a.

A **major light** is a high-intensity light exhibited from a fixed structure or a marine site. Major lights include primary seacoast lights and secondary lights. **Primary seacoast lights** are those major lights established for making landfall from sea and coastwise passages from headland to headland. **Secondary lights** are those major lights established at harbor entrances and other locations where high intensity and reliability are required.

A **minor light** usually displays a light of low to moderate intensity. Minor lights are established in harbors, along channels, rivers, and in isolated locations. They usually have numbering, coloring, and light and sound characteristics that are part of the lateral system of buoyage.

Lighthouses are placed where they will be of most use: on prominent headlands, at harbor and port entrances, on isolated dangers, or at other points where mariners can best use them to fix their position. The lighthouse’s principal purpose is to support a light at a considerable height above the water, thereby increasing its geographic range. Support equipment is often housed near the tower.

With few exceptions, all major lights are operated automatically. There are also many automatic lights on smaller structures maintained by the Coast Guard or other attendants. Unmanned major lights may have emergency generators and automatic monitoring equipment to increase the light’s reliability.

Light structures’ appearances vary. Lights in low-lying areas usually are supported by tall towers; conversely, light structures on high cliffs may be relatively short. However its support tower is constructed, almost all lights are similarly generated, focused, colored, and characterized.

Some major lights use modern rotating or flashing lights, but many older lights use **Fresnel** lenses. These lenses consist of intricately patterned pieces of glass in a heavy brass framework. Modern Fresnel-type lenses are cast from high-grade plastic; they are much smaller and lighter than their glass counterparts.

A **buoyant beacon** provides nearly the positional accuracy of a light in a place where a buoy would normally be used. See Figure 501b. The buoyant beacon consists of a heavy sinker to which a pipe structure is tightly moored. A buoyancy chamber near the surface supports the pipe. The light, radar reflector, and other devices are located atop the pipe above the surface of the water. The pipe with its buoyancy chamber tends to remain upright even in severe weather and heavy currents, providing a smaller watch circle than a buoy. The buoyant beacon is most useful along narrow ship channels in relatively sheltered water.

Figure 501a. Typical offshore light station.

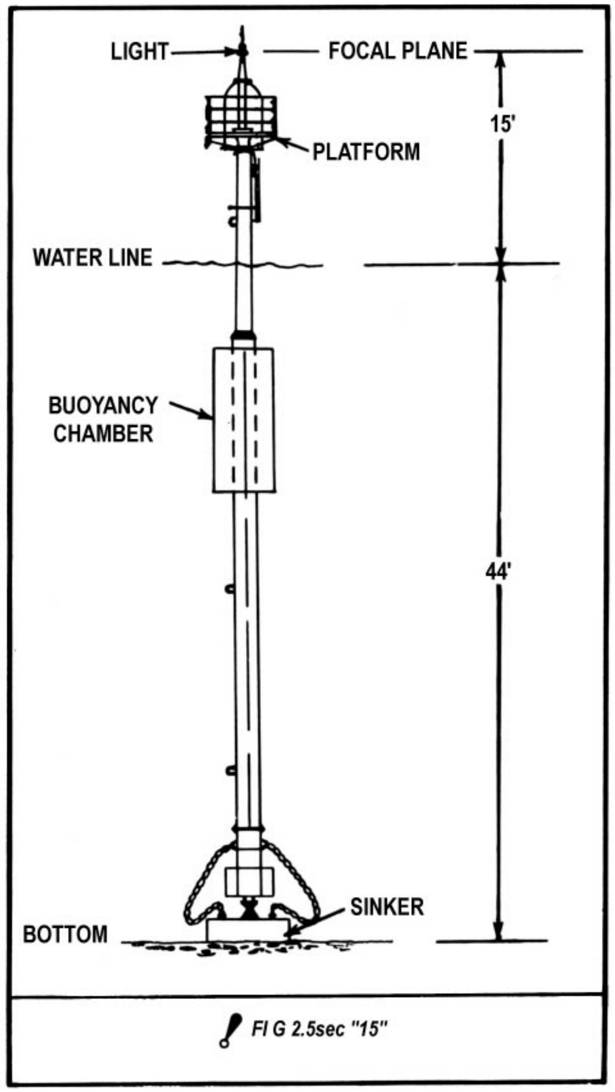


Figure 501b. Typical design for a buoyant beacon.

502. Range Lights

Range lights are light pairs that indicate a specific line of position when they are in line. The higher rear light is placed behind the front light. When the mariner sees the lights vertically in line, he is on the range line. If the front light appears left of the rear light, the observer is to the right of the rangeline; if the front appears to the right of the rear, the observer is left of the rangeline. Range lights are sometimes equipped with high intensity lights for daylight use. These are effective for long channels in hazy conditions when dayboards might not be seen. The range light structures are usually also equipped with dayboards for ordinary daytime use. Some smaller ranges, primarily in the Intracoastal Waterway and other inland waters, have just the dayboards with no lights. See Figure 502.

To enhance the visibility of range lights, the Coast Guard has developed 15-foot long lighted tubes called **light pipes**. They are mounted vertically, and the mariner sees them as vertical bars of light distinct from background lighting. Installation of light pipes is proceeding on several range markers throughout the country. The Coast Guard is also experimenting with long range sodium lights for areas requiring visibility greater than the light pipes can provide.

The output from a low pressure sodium light is almost entirely at one wavelength. This allows the use of an inexpensive band-pass filter to make the light visible even during the daytime. This arrangement eliminates the need for high intensity lights with their large power requirements.

Range lights are usually white, red, or green. They display various characteristics differentiating them from surrounding lights.

A **directional light** is a single light that projects a high intensity, special characteristic beam in a given direction. It is used in cases where a two-light range may not be practicable. A **directional sector light** is a directional light that emits two or more colored beams. The beams have a precisely oriented boundary between them. A normal application of a sector light would show three colored sections: red, white, and green. The white sector would indicate that the vessel is on the channel centerline; the

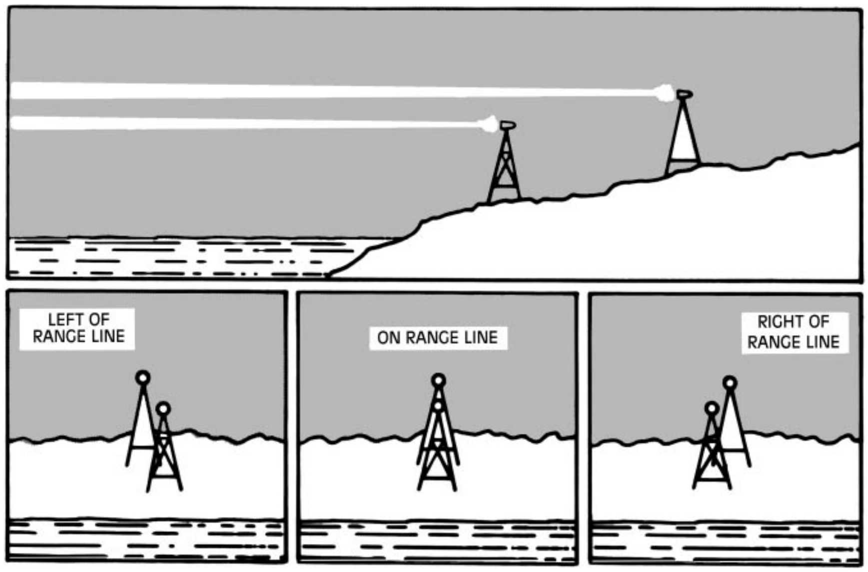


Figure 502. Range lights.

green sector would indicate that the vessel is off the channel centerline in the direction of deep water; and the red sector would indicate that the vessel is off the centerline in the direction of shoal water.

503. Aeronautical Lights

Aeronautical lights may be the first lights observed at night when approaching the coast. Those situated near the coast and visible from sea are listed in the *List of Lights*. These lights are not listed in the Coast Guard *Light List*. They usually flash alternating white and green.

Aeronautical lights are sequenced geographically in the *List of Lights* along with marine navigation lights. However, since they are not maintained for marine navigation, they are subject to changes of which maritime authorities may not be informed. These changes will be published in *Notice to Airmen* but perhaps not in *Notice To Mariners*.

504. Bridge Lights

Red, green, and white lights mark bridges across navigable waters of the United States. Red lights mark piers and other parts of the bridge. Red lights are also used on drawbridges to show when they are in the closed position. Green lights mark open drawbridges and mark the centerline of navigable channels through fixed bridges. The position will vary according to the type of structure. Navigational lights on bridges in the U.S. are prescribed by Coast Guard regulations.

Infrequently-used bridges may be unlighted. In foreign waters, the type and method of lighting may be different from those normally found in the United States. Drawbridges which must be opened to allow passage operate upon sound and light signals given by the vessel and acknowledged by the bridge. These required signals are detailed in the Code of Federal Regulations and the applicable Coast Pilot. Certain bridges may also be equipped with sound signals and radar reflectors.

505. Shore Lights

Shore lights usually have a shore-based power supply. Lights on pilings, such as those found in the Intracoastal Waterway, are battery powered. Solar panels may be installed to enhance the light's power supply. The lights consist of a power source, a flasher to determine the characteristic, a lamp changer to replace burned-out lamps, and a focusing lens.

Various types of rotating lights are in use. They do not have flashers but remain continuously lit while a lens or reflector rotates around the horizon.

The whole light system is carefully engineered to provide the maximum amount of light to the mariner for the least power use. Specially designed filaments and special grades of materials are used in the light to withstand the harsh marine environment.

The **flasher** electronically determines the characteristic by selectively interrupting the light's power supply according to the chosen cycle.

The **lamp changer** consists of several sockets arranged around a central hub. When the circuit is broken by a burned-out filament, a new lamp is rotated into position. Almost all lights have daylight switches which turn the light off at sunrise and on at dusk.

The **lens** for small lights may be one of several types. The common ones in use are omni-directional lenses of 155mm, 250mm, and 300mm. In addition, lights using parabolic mirrors or focused-beam lenses are used in leading lights and ranges. The lamp filaments must be carefully aligned with the plane of the lens or mirror to provide the maximum output of light. The lens' size is chosen according to the type of platform, power source, and lamp characteris-

tics. Additionally, environmental characteristics of the location are considered. Various types of light-condensing panels, reflex reflectors, or colored sector panels may be installed inside the lens to provide the proper characteristic.

A special heavy 200mm lantern is used in locations where ice and breaking water are a hazard.

LIGHT CHARACTERISTICS

506. Characteristics

A light has distinctive **characteristics** which distinguish it from other lights or convey specific information. A light may show a distinctive sequence of light and dark intervals. Additionally, a light may display a distinctive color or color sequence. In the Light Lists, the dark intervals are referred to as **eclipses**. An **occulting** light is a light totally eclipsed at regular intervals, the duration of light always being *greater* than the duration of darkness. A **flashing** light is a light which flashes at regular intervals, the duration of light always being *less* than the duration of darkness. An **isophase** light flashes at regular intervals, the duration of light being *equal* to the duration of darkness.

Light phase characteristics (Figure 506a and Figure 506b) are the distinctive sequences of light and dark intervals or sequences in the variations of the luminous intensity of a light. The light phase characteristics of lights which change color do not differ from those of lights which do not change color. A light showing different colors alternately is described as an **alternating** light. The alternating characteristic may be used with other light phase characteristics.

Light-sensitive switches extinguish most lighted navigation aids during daylight hours. However, owing to the various sensitivity of the light switches, all lights do not come on or go off at the same time. Mariners should account for this when identifying aids to navigation during twilight periods when some lighted aids are on while others are not.

507. Light Sectors

Sectors of colored glass or plastic are sometimes placed in the lanterns of certain lights to indicate dangerous waters. Lights so equipped show different colors when observed from different bearings. A sector changes the color of a light, but not its characteristic, when viewed from certain directions. For example, a four second flashing white light having a red sector will appear as a four second flashing red light when viewed from within the red sector.

Sectors may be only a few degrees in width or extend in a wide arc from deep water toward shore. Bearings referring to sectors are expressed in degrees true *as observed from a vessel*.

In most cases, areas covered by red sectors should be avoided. The nature of the danger can be determined from the chart. In some cases a narrow sector may mark the best water across a shoal, or a turning point in a channel.

Sectors generated by shadow-casting filters do not have precise boundaries as directional sector lights do. Therefore, the transition from one color to another is not abrupt. The colors change through an arc of uncertainty of 2° or greater, depending on the optical design of the light. Therefore determining bearings by observing the color change is less accurate than obtaining a bearing with an azimuth circle.

508. Factors Affecting Range And Characteristics

The condition of the atmosphere has a considerable effect upon a light’s range. Sometimes lights are obscured by fog, haze, dust, smoke, or precipitation. On the other hand, refraction may cause a light to be seen farther than under ordinary circumstances. A light of low intensity will be easily obscured by unfavorable conditions of the atmosphere. For this reason, the intensity of a light should always be considered when looking for it in thick weather. Haze and distance may reduce the apparent duration of a light’s flash. In some conditions of the atmosphere, white lights may have a reddish hue. In clear weather green lights may have a more whitish hue.

Lights placed at great elevations are more frequently obscured by clouds, mist, and fog than those near sea level. In regions where ice conditions prevail, an unattended light’s lantern panes may become covered with ice or snow This may reduce the light’s luminous range and change the light’s observed color.

The distance from a light *cannot* be estimated by its apparent brightness. There are too many factors which can change the perceived intensity. Also, a powerful, distant light may sometimes be confused with a smaller, closer one with similar characteristics. Every light sighted should be carefully evaluated to determine if it is the one expected.

The presence of bright shore lights may make it difficult to distinguish navigational lights from background lighting. Lights may also be obscured by various shore obstructions, natural and man-made. The Coast Guard requests mariners to report these cases to the nearest Coast Guard station.

A light’s **loom** is seen through haze or the reflection from low-lying clouds when the light is beyond its geographic range. Only the most powerful lights can generate a loom. The loom may sometimes be sufficiently defined to obtain a bearing. If not, an accurate bearing on a light beyond geographic range may sometimes be obtained by ascending to a higher level where the light can be seen, and noting a star directly over the light. The bearing of the star can then be obtained from the navigating bridge and the bearing to the light plotted indirectly.

At short distances, some of the brighter flashing lights may show a faint continuous light, or faint flashes, between

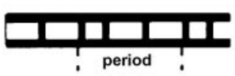
Illustration	Type Description	Abbreviation
	1. FIXED. A light showing continuously and steadily.	F
	2. OCCULTING. A light in which the total duration of light in a period is longer than the total duration of darkness and the intervals of darkness (eclopses) are usually of equal duration.	
	2.1 Single-occulting. An occulting light in which an eclipse is regularly repeated.	Oc
	2.2 Group-occulting. An occulting light in which a group of eclipses, specified in numbers, is regularly repeated.	Oc(2)
	2.3 Composite group-occulting. A light, similar to a group-occulting light, except that successive groups in a period have different numbers of eclipses.	Oc(2+1)
	3. ISOPHASE. A light in which all durations of light and darkness are equal.	Iso
	4. FLASHING. A flashing light in which the total duration of light in a period is shorter than the total duration of darkness and the appearances of light (flashes) are usually of equal duration.	
	4.1 Single-flashing. A flashing light in which a flash is regularly repeated (frequency not exceeding 30 flashes per minute).	Fl

Figure 506a. Light phase characteristics.

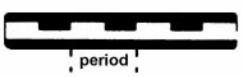
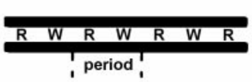
Illustration	Type Description	Abbreviation
	4.2 Group-flashing. A flashing light in which a group of glashes, specified in number, is regularly repeated.	Fl (2)
	4.3 Composite group-flashing. A light similar to a group flashing light except that successive groups in the period have different numbers of flashes.	Fl (2+1)
	5. QUICK. A light in which flashes are produced at a rate of 60 flashes per minute.	
	5.1 Contiuous quick. A quick light in which a flash is regulary repeated.	Q
	5.2 Interrupted quick. A quick light in which the sequence of flashes is interrupted by regulary repeated eclipses of constant and long duration.	IQ
	6. MORES CODE. A light in which the sequence of flashes is interrupted by regulary repeated eclipses of constant and long duration.	Mo (A)
	7. FIXED AND FLASHING. A quick light in which the sequence of flashes is interrupted by regulary repeated eclipses of constant and long duration.	FFl
	8. ALTERNATING. A light showing differenct colors alternately.	Al RW

Figure 506b. Light phase characteristics.

regular flashes. This is due to reflections of a rotating lens on panes of glass in the lighthouse.

If a light is not sighted within a reasonable time after prediction, a dangerous situation may exist. Conversely, the light may simply be obscured or extinguished. The ship's position should immediately be fixed by other means to determine any possibility of danger.

The apparent characteristic of a complex light may change with the distance of the observer. For example, a light with a characteristic of fixed white and alternating flashing white and red may initially show as a simple flashing white light. As the vessel draws nearer, the red flash will become visible and the characteristic will apparently be alternating flashing white and red. Later, the fainter fixed white light will be seen between the flashes and the true characteristic of the light finally recognized as fixed white, alternating flashing white and red (F W Al W R). This is because for a given candlepower, white is the most visible color, green less so, and red least of the three. This fact also accounts for the different ranges given in the Light Lists for some multi-color sector lights. The same lamp has different ranges according to the color imparted by the sector glass.

A light may be **extinguished** due to weather, battery failure, vandalism, or other causes. In the case of unattended lights, this condition might not be immediately corrected. The mariner should report this condition to the nearest Coast Guard station. During periods of armed conflict, certain lights may be deliberately extinguished without notice.

Offshore light stations should always be left well off the course whenever searoom permits.

BUOYS

509. Definitions And Types

Buoys are floating aids to navigation. They mark channels, indicate shoals and obstructions, and warn the mariner of dangers. Buoys are used where fixed aids would be uneconomical or impractical due to the depth of water. By their color, shape, topmark, number, and light characteristics, buoys indicate to the mariner how to avoid hazards and stay in safe water. The federal buoyage system in the U.S. is maintained by the Coast Guard.

There are many different sizes and types of buoys designed to meet a wide range of environmental conditions and user requirements. The size of a buoy is determined primarily by its location. In general, the smallest buoy which will stand up to local weather and current conditions is chosen.

There are five types of buoys maintained by the Coast Guard. They are:

1. Lateral marks.
2. Isolated danger marks.
3. Safe water marks.
4. Special marks.
5. Information/regulatory marks.

These conform in general to the specifications of the **International Association of Lighthouse Authorities (IALA)** buoyage system.

A **lighted buoy** is a floating hull with a tower on which a light is mounted. Batteries for the light are in watertight pockets in the buoy hull or in watertight boxes mounted on the buoy hull. To keep the buoy in an upright position, a counterweight is attached to the hull below the water surface. A radar reflector is built into the buoy tower.

The largest of the typical U.S. Coast Guard buoys can be moored in up to 190 feet of water, limited by the weight of chain the hull can support. The focal plane of the light is

Figure 509. Buoy showing counterweight.

15 to 20 feet high. The designed nominal visual range is 3.8 miles, and the radar range 4 miles. Actual conditions will cause these range figures to vary considerably.

The smallest buoys are designed for protected water. Some are made of plastic and weigh only 40 pounds. Specially designed buoys are used for fast current, ice, and other environmental conditions.

A variety of special purpose buoys are owned by other governmental organizations. Examples of these organizations include the Panama Canal Commission, the St. Lawrence Seaway Development Corporation, NOAA, and the Department of Defense. These buoys are usually navigational marks or data collection buoys with traditional round, boat-shaped, or discus-shaped hulls.

A special class of buoy, the **Ocean Data Acquisition System (ODAS)** buoy, is moored or floats free in offshore

waters. Positions are promulgated through radio warnings. These buoys are generally not large enough to cause damage in a collision, but should be given a wide berth regardless, as any loss would almost certainly result in the interruption of valuable scientific experiments. They are generally bright orange or yellow in color, with vertical stripes on moored buoys and horizontal bands on free-floating ones, and have a strobe light for night visibility.

Even in clear weather, the danger of collision with a buoy exists. If struck head-on, a large buoy can inflict severe damage to a large ship; it can sink a smaller one. Reduced visibility or heavy background lighting can contribute to the problem. The Coast Guard sometimes receives reports of buoys missing from station that were actually run down and sunk. Tugboats and towboats towing or pushing barges are particularly dangerous to buoys because of poor over-the-bow visibility when pushing or yawing during towing. The professional mariner must report *any* collision with a buoy to the nearest Coast Guard unit. Failure to do so may cause the next vessel to miss the channel or hit the obstruction marked by the buoy; it can also lead to fines and legal liability.

Routine on-station buoy maintenance consists of inspecting the mooring, cleaning the hull and superstructure, replacing the batteries, flasher, and lamps, checking wiring and venting systems, and verifying the buoy's exact position. Every few years, each buoy is replaced by a similar aid and returned to a Coast Guard maintenance facility for complete refurbishment.

The placement of a buoy depends on its purpose and its position on the chart. Most buoys are placed on charted position as accurately as conditions allow. However, if a buoy's purpose is to mark a shoal and the shoal is found to be in a different position than the chart shows, the buoy will be placed to properly mark the shoal, and not on its charted position.

510. Lights On Buoys

Buoy light systems consist of a **battery pack**, a **flasher** which determines the characteristic, a **lamp changer** which automatically replaces burned-out bulbs, a **lens** to focus the light, and a **housing** which supports the lens and protects the electrical equipment.

The **batteries** consist of 12-volt lead/acid type batteries electrically connected to provide sufficient power to run the proper flash characteristic and lamp size. These battery packs are contained in pockets in the buoy hull, accessible through water-tight bolted hatches or externally mounted boxes. Careful calculations based on light characteristics determine how much battery power to install.

The **flasher** determines the characteristic of the lamp. It is installed in the housing supporting the lens.

The **lamp changer** consists of several sockets arranged around a central hub. A new lamp rotates into position if the active one burns out.

Under normal conditions, the **lenses** used on buoys are 155mm in diameter at the base. 200 mm lenses are used where breaking waves or swells call for the larger lens. They are colored according to the charted characteristic of the buoy. As in shore lights, the lamp must be carefully focused so that the filament is directly in line with the focal plane of the lens. This ensures that the majority of the light produced is focused in a 360° horizontal fan beam A buoy light has a relatively narrow vertical profile. Because the buoy rocks in the sea, the focal plane may only be visible for fractions of a second at great ranges. A realistic range for sighting buoy lights is 4-6 miles in good visibility.

511. Sound Signals On Buoys

Lighted sound buoys have the same general configuration as lighted buoys but are equipped with either a bell, gong, whistle, or horn. **Bells** and **gongs** are sounded by tappers hanging from the tower that swing as the buoys roll in the sea. Bell buoys produce only one tone; gong buoys produce several tones. The tone-producing device is mounted between the legs of the pillar or tower.

Whistle buoys make a loud moaning sound caused by the rising and falling motions of the buoy in the sea. A sound buoy equipped with an electronic **horn** will produce a pure tone at regular intervals regardless of the sea state. Unlighted sound buoys have the same general appearance as lighted buoys, but their underwater shape is designed to make them lively in all sea states.

512. Buoy Moorings

Buoys require **moorings** to hold them in position. Typically the mooring consists of **chain** and a large concrete or cast iron **sinker**. See Figure 512. Because buoys are subjected to waves, wind, and tides, the moorings must be

Figure 512. A sinker used to anchor a buoy.

deployed with chain lengths much greater than the water depth. The scope of chain will normally be about 3 times the water depth. The length of the mooring chain defines a **watch circle** within which the buoy can be expected to swing. It is for this reason that the charted buoy symbol has a “position approximate” circle to indicate its charted position, whereas a light position is shown by a dot at the exact location. Actual watch circles do not necessarily coincide with the “position approximate” circles which represent them.

Over several years, the chain gradually wears out and must be replaced with new. The worn chain is often cast into the concrete of new sinkers.

513. Large Navigational Buoys

Large navigational buoys are moored in open water at approaches to major seacoast ports. These 40-foot diameter buoys (Figure 513) show lights from heights of about 36 feet above the water. Emergency lights automatically energize if the main light is extinguished. These buoys may also have a radiobeacon and sound signals. Their condition is monitored by radio from shore.

514. Wreck Buoys

A **wreck buoy** usually cannot be placed directly over the wreck it is intended to mark because the buoy tender may not want to pass over a shallow wreck or risk fouling the buoy mooring. For this reason, a wreck buoy is usually placed as closely as possible on the seaward or channelward side of a wreck. In some situations, two buoys may be used to mark the wreck, one lying off each end. The wreck may lie directly between them or inshore of a line between them, depending on the local situation. The *Local Notice To Mariners* should be consulted concerning details of the placement of wreck buoys on individual wrecks. Often it will also give particulars of the wreck and what activities may be in progress to clear it.

Figure 513. Large navigational buoy.

The charted position of a wreck buoy will usually be offset from the actual geographic position so that the wreck and buoy symbols do not coincide. Only on the largest scale chart will the actual and charted positions of both wreck and buoy be the same. Where they might overlap, it is the wreck symbol which occupies the exact charted position and the buoy symbol which is offset.

Wreck buoys are required to be placed by the owner of the wreck, but they may be placed by the Coast Guard if the owner is unable to comply with this requirement. In general, privately placed aids are not as reliable as Coast Guard aids.

Sunken wrecks are sometimes moved away from their buoys by storms, currents, freshets, or other causes. Just as shoals may shift away from the buoys placed to mark them, wrecks may shift away from wreck buoys.

515. Fallibility Of Buoys

Buoys cannot be relied on to maintain their charted positions consistently. They are subject to a variety of hazards including severe weather, collision, mooring casualties, and electrical failure. Report any discrepancy noted in a buoy to the U.S. Coast Guard.

The buoy symbol shown on charts indicates the approximate position of the sinker which secures the buoy to the seabed. The approximate position is used because of practical limitations in placing and keeping buoys and their sinkers in precise geographical locations. These limitations include prevailing atmospheric and sea conditions, the slope and type of material making up the seabed, the scope of the mooring chain, and the fact that the positions of the buoys and the sinkers are not under continuous surveillance. The position of the buoy shifts around the area shown by the chart symbol due to the forces of wind and current.

A buoy may not be in its charted position because of changes in the feature it marks. For example, a buoy meant to mark a shoal whose boundaries are shifting might frequently be moved to mark the shoal accurately. A *Local Notice To Mariners* will report the change, and a *Notice To Mariners* chart correction may also be written. In some small channels which change often, buoys are not charted even when considered permanent; local knowledge is advised in such areas.

For these reasons, a mariner must not rely completely upon the position or operation of buoys, but should navigate using bearings of charted features, structures, and aids to navigation on shore. Further, a vessel attempting to pass too close aboard a buoy risks a collision with the buoy or the obstruction it marks.

BUOYAGE SYSTEMS

516. Lateral And Cardinal Systems

There are two major types of buoyage systems: the **lateral system** and the **cardinal system**. The lateral system is best suited for well-defined channels. The description of each buoy indicates the direction of danger relative to the course which is normally followed. In principle, the positions of marks in the lateral system are determined by the **general direction** taken by the mariner when approaching port from seaward. These positions may also be determined with reference to the main stream of flood current. The United States Aids to Navigation System is a lateral system.

The cardinal system is best suited for coasts with numerous isolated rocks, shoals, and islands, and for dangers in the open sea. The characteristic of each buoy indicates the approximate true bearing of the danger it marks. Thus, an eastern quadrant buoy marks a danger which lies to the west of the buoy. The following pages diagram the cardinal and lateral buoyage systems as found outside the United States.

517. The IALA Maritime Buoyage System

Although most of the major maritime nations have used either the lateral or the cardinal system for many years, details such as the buoy shapes and colors have varied from country to country. With the increase in maritime commerce between countries, the need for a uniform system of buoyage became apparent.

In 1889, an International Marine Conference held in Washington, D.C., recommended that in the lateral system, starboard hand buoys be painted red and port hand buoys black. Unfortunately, when lights for buoys were introduced some years later, some European countries placed red lights on the black port hand buoys to conform with the red lights marking the port side of harbor entrances, while in North America red lights were placed on red starboard hand buoys. In 1936, a League of Nations subcommittee recommended a coloring system opposite to the 1889 proposal.

The **International Association of Lighthouse Authorities (IALA)** is a non-governmental organization which consists of representatives of the worldwide community of aids to navigation services to promote information exchange and recommend improvements based on new technologies. In 1980, with the assistance of IMO and the IHO, the lighthouse authorities from 50 countries and representatives of 9 international organizations concerned with aids to navigation met and adopted the **IALA Maritime Buoyage System**. They established two regions, **Region A** and **Region B**, for the entire world. Region A roughly corresponds to the 1936 League of Nations system, and Region B to the older 1889 system.

Lateral marks differ between Regions A and B. Lateral marks in Region A use red and green colors by day and night

to indicate port and starboard sides of channels, respectively. In Region B, these colors are reversed with red to starboard and green to port. In both systems, the conventional direction of buoyage is considered to be *returning from sea*, hence the phrase “red right returning” in IALA region B.

518. Types Of Marks

The **IALA Maritime Buoyage System** applies to all fixed and floating marks, other than lighthouses, sector lights, leading lights and daymarks, lightships and large navigational buoys, and indicates:

1. The side and center-lines of navigable channels.
2. Natural dangers, wrecks, and other obstructions.
3. Regulated navigation areas.
4. Other important features.

Most lighted and unlighted beacons other than leading marks are included in the system. In general, beacon topmarks will have the same shape and colors as those used on buoys. The system provides five types of marks which may be used in any combination:

1. Lateral marks indicate port and starboard sides of channels.
2. Cardinal marks, named according to the four points of the compass, indicate that the navigable water lies to the named side of the mark.
3. Isolated danger marks erected on, or moored directly on or over, dangers of limited extent.
4. Safe water marks, such as midchannel buoys.
5. Special marks, the purpose of which is apparent from reference to the chart or other nautical documents.

Characteristics Of Marks

The significance of a mark depends on one or more features:

1. By day—color, shape, and topmark.
2. By night—light color and phase characteristics.

Colors Of Marks

The colors red and green are reserved for lateral marks, and yellow for special marks. The other types of marks have black and yellow or black and red horizontal bands, or red and white vertical stripes.

Shapes Of Marks

There are five basic buoy shapes:

1. Can.
2. Cone.
3. Sphere.
4. Pillar.
5. Spar.

In the case of can, conical, and spherical, the shapes have lateral significance because the shape indicates the correct side to pass. With pillar and spar buoys, the shape has no special significance.

The term “pillar” is used to describe any buoy which is smaller than a “large navigation buoy (LNB)” and which has a tall, central structure on a broad base; it includes beacon buoys, high focal plane buoys, and others (except spar buoys) whose body shape does not indicate the correct side to pass.

Topmarks

The IALA System makes use of **can, conical, spherical,** and **X-shaped** topmarks only. Topmarks on pillar and spar buoys are particularly important and will be used wherever practicable, but ice or other severe conditions may occasionally prevent their use.

Colors Of Lights

Where marks are lighted, red and green lights are reserved for lateral marks, and yellow for special marks. The other types of marks have a white light, distinguished one from another by phase characteristic.

Phase Characteristics Of Lights

Red and green lights may have any phase characteristic, as the color alone is sufficient to show on which side they should be passed. Special marks, when lighted, have a yellow light with any phase characteristic not reserved for white lights of the system. The other types of marks have clearly specified phase characteristics of white light: various quick-flashing phase characteristics for cardinal marks, group flashing (2) for isolated danger marks, and relatively long periods of light for safe water marks.

Some shore lights specifically excluded from the IALA System may coincidentally have characteristics corresponding to those approved for use with the new marks. Care is needed to ensure that such lights are not misinterpreted.

519. IALA Lateral Marks

Lateral marks are generally used for well-defined channels; they indicate the port and starboard hand sides of the route to be followed, and are used in conjunction with a **conventional direction of buoyage**.

This direction is defined in one of two ways:

1. **Local direction of buoyage** is the direction taken by the mariner when approaching a harbor, river estuary, or other waterway from seaward.

2. **General direction of buoyage** is determined by the buoyage authorities, following a clockwise direction around continental land-masses, given in sailing directions, and, if necessary, indicated on charts by a large open arrow symbol.

In some places, particularly straits open at both ends, the local direction of buoyage may be overridden by the general direction.

Along the coasts of the United States, the characteristics assume that proceeding "from seaward" constitutes a clockwise direction: a southerly direction along the Atlantic coast, a westerly direction along the Gulf of Mexico coast, and a northerly direction along the Pacific coast. On the Great Lakes, a westerly and northerly direction is taken as being "from seaward" (except on Lake Michigan, where a southerly direction is used). On the Mississippi and Ohio Rivers and their tributaries, the characteristics of aids to navigation are determined as proceeding from sea toward the head of navigation. On the Intracoastal Waterway, proceeding in a generally southerly direction along the Atlantic coast, and in a generally westerly direction along the gulf coast, is considered as proceeding "from seaward."

520. IALA Cardinal Marks

A **cardinal mark** is used in conjunction with the compass to indicate where the mariner may find the best navigable water. It is placed in one of the four quadrants (north, east, south, and west), bounded by the true bearings NW-NE, NE-SE, SE-SW, and SW-NW, taken from the point of interest. A cardinal mark takes its name from the quadrant *in which it is placed*.

The mariner is safe if he passes north of a north mark, east of an east mark, south of a south mark, and west of a west mark.

A cardinal mark may be used to:

1. Indicate that the deepest water in an area is on the named side of the mark.
2. Indicate the safe side on which to pass a danger.
3. Emphasize a feature in a channel, such as a bend, junction, bifurcation, or end of a shoal.

Topmarks

Black double-cone topmarks are the most important feature, by day, of cardinal marks. The cones are vertically placed, one over the other. The arrangement of the cones is very logical: North is two cones with their points up (as in "north-up"). South is two cones, points down. East is two cones with bases together, and west is two cones with points together, which gives a wineglass shape. "<u>W</u>est is a <u>W</u>ineglass" is a memory aid.

Cardinal marks carry topmarks whenever practicable, with the cones as large as possible and clearly separated.

Colors

Black and yellow horizontal bands are used to color a cardinal mark. The position of the black band, or bands, is related to the points of the black topmarks.

N	Points up	Black above yellow.
S	Points down	Black below yellow.
W	Points together	Black, yellow above and below.
E	Points apart	Yellow, black above and below.

Shape

The shape of a cardinal mark is not significant, but buoys must be pillars or spars.

Lights

When lighted, a cardinal mark exhibits a white light; its characteristics are based on a group of quick or very quick flashes which distinguish it as a cardinal mark and indicate its quadrant. The distinguishing quick or very quick flashes are:

North—Uninterrupted
East—three flashes in a group
South—six flashes in a group followed by a long flash
West—nine flashes in a group

As a memory aid, the number of flashes in each group can be associated with a clock face as follows:
(3 o'clock—E, 6 o'clock—S, and 9 o'clock—W).

The long flash (of not less than 2 seconds duration), immediately following the group of flashes of a south cardinal mark, is to ensure that its six flashes cannot be mistaken for three or nine.

The periods of the east, south, and west lights are, respectively, 10, 15, and 15 seconds if quick flashing; and 5, 10, and 10 seconds if very quick flashing.

Quick flashing lights flash at a rate between 50 and 79 flashes per minute, usually either 50 or 60. Very quick flashing lights flash at a rate between 80 and 159 flashes per minute, usually either 100 or 120.

It is necessary to have a choice of quick flashing or very quick flashing lights in order to avoid confusion if, for example, two north buoys are placed near enough to each other for one to be mistaken for the other.

521. IALA Isolated Danger Marks

An **isolated danger mark** is erected on, or moored on or above, an isolated danger of limited extent which has navigable water all around it. The extent of the surrounding navigable water is immaterial; such a mark can, for example, indicate either a shoal which is well offshore or an islet separated by a narrow channel from the coast.

Position

On a chart, the position of a danger is the center of the symbol or sounding indicating that danger; an isolated danger buoy may therefore be slightly displaced from its geographic position to avoid overprinting the two symbols. The smaller the scale, the greater this offset will be. At very large scales the symbol may be correctly charted.

Topmark

A black double-sphere topmark is, by day, the most important feature of an isolated danger mark. Whenever practicable, this topmark will be carried with the spheres as large as possible, disposed vertically, and clearly separated.

Color

Black with one or more red horizontal bands are the colors used for isolated danger marks.

Shape

The shape of an isolated danger mark is not significant, but a buoy will be a pillar or a spar.

Light

When lighted, a white flashing light showing a group of two flashes is used to denote an isolated danger mark. As a memory aid, associate two flashes with two balls in the topmark.

522. IALA Safe Water Marks

A **safe water mark** is used to indicate that there is navigable water all around the mark. Such a mark may be used as a center line, mid-channel, or landfall buoy.

Color

Red and white vertical stripes are used for safe water marks, and distinguish them from the black-banded, danger-marking marks.

Shape

Spherical, pillar, or spar buoys may be used as safe water marks.

Topmark

A single red spherical topmark will be carried, whenever practicable, by a pillar or spar buoy used as a safe water mark.

Lights

When lighted, safe water marks exhibit a white light. This light can be occulting, isophase, a single long flash, or Morse “A.” If a long flash (i.e. a flash of not less than 2 seconds) is used, the period of the light will be 10 seconds. As a memory aid, remember a single flash and a single sphere topmark.

523. IALA Special Marks

A **special mark** may be used to indicate a special area or feature which is apparent by referring to a chart, sailing directions, or notices to mariners. Uses include:

1. Ocean Data Acquisition System (ODAS) buoys.
2. Traffic separation marks.
3. Spoil ground marks.
4. Military exercise zone marks.
5. Cable or pipeline marks, including outfall pipes.
6. Recreation zone marks.

Another function of a special mark is to define a channel within a channel. For example, a channel for deep draft vessels in a wide estuary, where the limits of the channel for normal navigation are marked by red and green lateral buoys, may have its boundaries or centerline marked by yellow buoys of the appropriate lateral shapes.

Color

Yellow is the color used for special marks.

Shape

The shape of a special mark is optional, but must not conflict with that used for a lateral or a safe water mark. For example, an outfall buoy on the port hand side of a channel could be can-shaped but not conical.

Topmark

When a topmark is carried it takes the form of a single yellow X.

Lights

When a light is exhibited it is yellow. It may show any phase characteristic except those used for the white lights of cardinal, isolated danger, and safe water marks, In the case of ODAS buoys, the phase characteristic used is group-flashing with a group of five flashes every 20 seconds.

524. IALA New Dangers

A newly discovered hazard to navigation not yet shown

on charts, included in sailing directions, or announced by a *Notice To Mariners* is termed a **new danger**. The term covers naturally occurring and man-made obstructions.

Marking

A new danger is marked by one or more cardinal or lateral marks in accordance with the IALA system rules. If the danger is especially grave, at least one of the marks will be duplicated as soon as practicable by an identical mark until the danger has been sufficiently identified.

Lights

If a lighted mark is used for a new danger, it must exhibit a quick flashing or very quick flashing light. If a cardinal mark is used, it must exhibit a white light; if a lateral mark, a red or green light.

Racons

The duplicate mark may carry a Racon, Morse coded D, showing a signal length of 1 nautical mile on a radar display.

525. Chart Symbols And Abbreviations

Spar buoys and spindle buoys are represented by the same symbol; it is slanted to distinguish them from upright beacon symbols. The abbreviated description of the color of a buoy is given under the symbol. Where a buoy is colored in bands, the colors are indicated in sequence from the top. If the sequence of the bands is not known, or if the buoy is striped, the colors are indicated with the darker color first.

Topmarks

Topmark symbols are solid black except when the topmark is red.

Lights

The period of the light of a cardinal mark is determined by its quadrant and its flash characteristic (either quick-flashing or a very quick-flashing). The light's period is less important than its phase characteristic. Where space on charts is limited, the period may be omitted.

Light flares

Magenta light-flares are normally slanted and inserted with their points adjacent to the position circles at the base of the symbols so the flare symbols do not obscure the topmark symbols.

Radar Reflectors

Radar reflectors are not affected by the IALA buoyage rules. They are not charted for several reasons. It can be assumed that most major buoys are fitted with radar reflectors. It is also necessary to reduce the size and complexity of buoy symbols and associated legends. Finally, it is understood that, in the case of cardinal buoys, buoyage authorities site the reflector so that it cannot be mistaken for a topmark. For these reasons, radar reflectors are not charted under IALA rules.

The symbols and abbreviations of the IALA Maritime Buoyage System may be found in U.S.. Chart No. 1, Nautical Chart Symbols and Abbreviations, and in foreign equivalents.

526. Description Of The U.S. Aids to Navigation System

In the United States, the U.S. Coast Guard has incorporated the major features of the IALA system with the existing infrastructure of buoys and lights as explained below.

Colors

Under this system, green buoys mark a channel's port side and obstructions which must be passed by keeping the buoy on the port hand. Red buoys mark a channel's starboard side and obstructions which must be passed by keeping the buoy on the starboard hand.

Red and green horizontally banded **preferred channel buoys** mark junctions or bifurcations in a channel or obstructions which may be passed on either side. If the topmost band is green, the preferred channel will be followed by keeping the buoy on the port hand. If the topmost band is red, the preferred channel will be followed by keeping the buoy on the starboard hand.

Red and white vertically striped safe water buoys mark a fairway or mid-channel.

Reflective material is placed on buoys to assist in their detection at night with a searchlight. The color of the reflective material agrees with the buoy color. Red or green reflective material may be placed on preferred channel (junction) buoys; red if topmost band is red or green if the topmost band is green. White reflective material is used on safe water buoys. Special purpose buoys display yellow reflective material. Warning or regulatory buoys display orange reflective horizontal bands and a warning symbol. Intracoastal Waterway buoys display a yellow reflective square, triangle, or horizontal strip along with the reflective material coincident with the buoy's function.

Shapes

Certain unlighted buoys are differentiated by shape. Red buoys and red and green horizontally banded buoys with the topmost band red are cone-shaped buoys called **nuns**. Green buoys and green and red horizontally banded buoys with the topmost band green are cylinder-shaped buoys called **cans**.

Unlighted red and white vertically striped buoys may be pillar shaped or spherical. Lighted buoys, sound buoys, and spar

buoys are not differentiated by shape to indicate the side on which they should be passed. Their purpose is indicated not by shape but by the color, number, or light characteristics.

Numbers

All solid colored buoys are numbered, red buoys bearing even numbers and green buoys bearing odd numbers. (Note that this same rule applies in IALA System A also.) The numbers increase from seaward upstream or toward land. No other colored buoys are numbered; however, any buoy may have a letter for identification.

Light colors

Red lights are used only on red buoys or red and green horizontally banded buoys with the topmost band red. Green lights are used only on the green buoys or green and red horizontally banded buoys with the topmost band green. White lights are used on both "safe water" aids showing a Morse A characteristic and on Information and Regulatory aids.

Light Characteristics

Lights on red buoys or green buoys, if not occulting or isophase, will generally be regularly flashing (Fl). For ordinary purposes, the frequency of flashes will be not more than 50 flashes per minute. Lights with a distinct cautionary significance, such as at sharp turns or marking dangerous obstructions, will flash not less than 50 flashes but not more than 80 flashes per minute (quick flashing, Q). Lights on preferred channel buoys will show a series of grouped flashes with successive groups in a period having different number of flashes—composite group flashing (or a quick light in which the sequence of flashes is interrupted by regularly repeated eclipses of constant and long duration). Lights on safe water buoys will always show a white Morse Code "A" (Short-Long) flash recurring at the rate of approximately eight times per minute.

Daylight Controls

Lighted buoys have a special device to energize the light when darkness falls and to de-energize the light when day breaks. These devices are not of equal sensitivity; therefore all lights do not come on or go off at the same time. Mariners should ensure correct identification of aids during twilight periods when some light aids to navigation are on while others are not.

Special Purpose Buoys

Buoys for special purposes are colored yellow. White buoys with orange bands are for information or regulatory purposes. The shape of special purpose buoys has no significance. They are not numbered, but they may be lettered. If lighted, special purpose buoys display a yellow light usually with fixed or slow flash characteristics. Information and regulatory buoys, if lighted, display white lights.

BEACONS

527. Definition And Description

Beacons are fixed aids to navigation placed on shore or on pilings in relatively shallow water. If unlighted, the beacon is referred to as a **daybeacon**. A daybeacon is identified by its color and the color, shape, and number of its **dayboard**. The simplest form of daybeacon consists of a single pile with a dayboard affixed at or near its top. See Figure 527. Daybeacons may be used to form an unlighted range.

Dayboards identify aids to navigation against daylight backgrounds. The size of the dayboard required to make the aid conspicuous depends upon the aid's intended range.

Most dayboards also display numbers or letters for identification. The numbers, letters, and borders of most dayboards have reflective tape to make them visible at night.

The detection, recognition, and identification distances vary widely for any particular dayboard. They depend upon the luminance of the dayboard, the sun's position, and the local visibility conditions.

Figure 527. Daybeacon.

SOUND SIGNALS

528. Types Of Sound Signals

Most lighthouses and offshore light platforms, as well as some minor light structures and buoys, are equipped with sound-producing devices to help the mariner in periods of low visibility. Charts and Light Lists contain the information required for positive identification. Buoys fitted with bells, gongs, or whistles actuated by wave motion may produce no sound when the sea is calm. Sound signals are not designed to identify the buoy or beacon for navigation purposes. Rather, they allow the mariner to pass clear of the buoy or beacon during low visibility.

Sound signals vary. The navigator must use the Light List to determine the exact length of each blast and silent interval. The various types of sound signals also differ in tone, facilitating recognition of the respective stations.

Diaphones produce sound with a slotted piston moved back and forth by compressed air. Blasts may consist of a high and low tone. These alternate-pitch signals are called “two-tone.” Diaphones are not used by the Coast Guard, but the mariner may find them on some private navigation aids.

Horns produce sound by means of a disc diaphragm operated pneumatically or electrically. Duplex or triplex horn units of differing pitch produce a chime signal.

Sirens produce sound with either a disc or a cup-shaped rotor actuated electrically or pneumatically. Sirens are not used on U.S. navigation aids.

Whistles use compressed air emitted through a circumferential slot into a cylindrical bell chamber.

Bells and gongs are sounded with a mechanically operated hammer.

529. Limitations Of Sound Signals

As aids to navigation, sound signals have serious limitations because sound travels through the air in an unpredictable manner.

It has been clearly established that:

1. Sound signals are heard at greatly varying distances and that the distance at which a sound signal can be heard may vary with the bearing and timing of the signal.
2. Under certain atmospheric conditions, when a sound signal has a combination high and low tone, it is not unusual for one of the tones to be inaudible. In the case of sirens, which produce a varying tone, portions of the signal may not be heard.
3. When the sound is screened by an obstruction, there are areas where it is inaudible.
4. Operators may not activate a remotely controlled sound aid for a condition unobserved from the controlling station.
5. Some sound signals cannot be immediately started.
6. The status of the vessel’s engines and the location of the observer both affect the effective range of the aid.

These considerations justify the utmost caution when navigating near land in a fog. A navigator can never rely on sound signals alone; he should continuously man both the radar and fathometer. He should place lookouts in positions where the noises in the ship are least likely to interfere with hearing a sound signal. The aid upon which a sound signal rests is usually a good radar target, but collision with the aid or the danger it marks is always a possibility.

Emergency signals are sounded at some of the light and fog signal stations when the main and stand-by sound signals are inoperative. Some of these emergency sound signals are of a different type and characteristic than the main sound signal. The characteristics of the emergency sound signals are listed in the Light List.

The mariner should never assume:

1. That he is out of ordinary hearing distance because he fails to hear the sound signal.
2. That because he hears a sound signal faintly, he is far from it.
3. That because he hears it clearly, he is near it.
4. That the distance from and the intensity of a sound on any one occasion is a guide for any future occasion.
5. That the sound signal is not sounding because he does not hear it, even when in close proximity.
6. That the sound signal is in the direction the sound appears to come from.

MISCELLANEOUS U.S. SYSTEMS

530. Intracoastal Waterway Aids To Navigation

The Intracoastal Waterway (ICW) runs parallel to the Atlantic and Gulf of Mexico coasts from Manasquan Inlet on the New Jersey shore to the Texas/Mexican border. It follows rivers, sloughs, estuaries, tidal channels, and other natural waterways, connected with dredged channels where necessary. Some of the aids marking these waters are marked with yellow; otherwise, the marking of buoys and beacons follows the same system as that in other U.S. waterways.

Yellow symbols indicate that an aid marks the Intracoastal Waterway. Yellow triangles indicate starboard hand aids, and yellow squares indicate port hand aids when following the ICW's conventional direction of buoyage. Non-lateral aids such as safe water, isolated danger, and front range boards are marked with a horizontal yellow band. Rear range boards do not display the yellow band. At a junction with a federally-maintained waterway, the preferred channel mark will display a yellow triangle or square as appropriate. Junctions between the ICW and privately maintained waterways are not marked with preferred channel buoys.

531. Western Rivers System

Aids to navigation on the Mississippi River and its tributaries above Baton Rouge generally conform to the lateral system of buoyage in use in the rest of the U.S. The following differences are significant:

1. Buoys are not numbered.
2. The numbers on lights and daybeacons do not have lateral significance; they indicate the mileage from a designated point, normally the river mouth.
3. Flashing lights on the left side proceeding upstream show single green or white flashes while those on the right side show group flashing red or white flashes.
4. Diamond shaped crossing daymarks are used to indicate where the channel crosses from one side of the river to the other.

532. The Uniform State Waterway Marking System (USWMS)

This system was developed jointly by the U.S. Coast Guard and state boating administrators to assist the small craft operator in those state waters marked by participating states. The **USWMS** consists of two categories of aids to navigation. The first is a system of aids to navigation, generally compatible with the Federal lateral system of buoyage, supplementing the federal system in state waters. The other is a system of regulatory markers to warn small craft operator of dangers or to provide general information.

On a well-defined channel, red and black buoys are established in pairs called **gates**; the channel lies between the buoys. The buoy which marks the left side of the channel viewed looking upstream or toward the head of navigation is black; the buoy which marks the right side of the channel is red.

In an irregularly-defined channel, buoys may be staggered on alternate sides of the channel, but they are spaced at sufficiently close intervals to mark clearly the channel lying between them.

When there is no well-defined channel or when a body of water is obstructed by objects whose nature or location is such that the obstruction can be approached by a vessel from more than one direction, aids to navigation having cardinal significance may be used. The aids conforming to the cardinal system consist of three distinctly colored buoys.

1. A white buoy with a red top must be passed to the south or west of the buoy.
2. A white buoy with a black top must be passed to the north or east of the buoy.
3. A buoy showing alternate vertical red and white stripes indicates that an obstruction to navigation extends from the nearest shore to the buoy and that he must not pass between the buoy and the nearest shore.

The shape of buoys has no significance under the USWMS.

Regulatory buoys are colored white with orange horizontal bands completely around them. One band is at the top of the buoy and a second band just above the waterline of the buoy so that both orange bands are clearly visible.

Geometric shapes colored orange are placed on the white portion of the buoy body. The authorized geometric shapes and meanings associated with them are as follows:

1. A vertical open faced diamond shape means danger.
2. A vertical open faced diamond shape with a cross centered in the diamond means that vessels are excluded from the marked area.
3. A circular shape means that vessels in the marked area are subject to certain operating restrictions.
4. A square or rectangular shape indicates that directions or information is written inside the shape.

Regulatory markers consist of square and rectangular shaped signs displayed from fixed structures. Each sign is white with an orange border. Geometric shapes with the same meanings as those displayed on buoys are centered on the sign boards. The geometric shape displayed on a regulatory marker tells the mariner if he should stay well clear of the marker or if he may approach the marker in order to read directions.

533. Private Aids To Navigation

A **private navigation aid** is any aid established and maintained by entities other than the Coast Guard.

The Coast Guard must approve the placement of private navigation aids. In addition, the District Engineer, U.S. Army Corps of Engineers, must approve the placement of any structure, including aids to navigation, in the navigable waters of the U.S.

Private aids to navigation are similar to the aids established and maintained by the U.S. Coast Guard; they are

specially designated on the chart and in the Light List. In some cases, particularly on large commercial structures, the aids are the same type of equipment used by the Coast Guard. Although the Coast Guard periodically inspects some private navigation aids, the mariner should exercise special caution when using them.

In addition to private aids to navigation, numerous types of construction and anchor buoys are used in various oil drilling operations and marine construction. These buoys are not charted, as they are temporary, and may not be lighted well or at all. Mariners should give a wide berth to drilling and construction sites to avoid the possibility of fouling moorings. This is a particular danger in offshore oil fields, where large anchors are often used to stabilize the positions of drill rigs in deep water. Up to eight anchors may be placed at various positions as much as a mile from the drill ship. These may or may not be marked by buoys.

534. Protection By Law

It is unlawful to impair the usefulness of any navigation aid established and maintained by the United States. If any vessel collides with an navigation aid, it is the legal duty of the person in charge of the vessel to report the accident to the nearest U.S. Coast Guard station.

CHAPTER 6

MAGNETIC COMPASS ADJUSTMENT

GENERAL PROCEDURES FOR MAGNETIC COMPASS ADJUSTMENT

600. Introduction

This chapter presents information and procedures for magnetic compass adjustment. Sections 601 and 613 cover procedures designed to eliminate compass errors satisfactorily. Refer to Figure 607 for condensed information regarding the various compass errors and their correction.

The term **compass adjustment** refers to any change of permanent magnet or soft iron correctors to reduce normal compass errors. The term **compass compensation** refers to any change in the current slupplied to the compass compensating coils to reduce degaussing errors.

601. Adjustment Check-Off List

If the magnetic adjustment necessitates (a) movement of degaussing compensating coils, or (b) a change of Flinders bar length, check also the coil compensation per section 646.

Expeditious compass adjustment depends on the application of the various correctors in an optimum sequence designed to minimize the number of correction steps. Certain adjustments may be made conveniently at dockside, simplifying the at sea adjustment procedures.

Moving the wrong corrector wastes time and upsets all previous adjustments, so be careful to make the correct adjustments. Throughout an adjustment, special care should be taken to pair off spare magnets so that the resultant field about them will be negligible. To make doubly sure that the compass is not affected by a spare magnet's stray field, keep them at an appropriate distance until they are actually inserted into the binnacle.

A. Dockside tests and adjustments.

1. Physical checks on the compass and binnacle.
    a. Remove any bubbles in compass bowl (section 610).
    b. Test for moment and sensibility of compass needles (section 610).
    c. Remove any slack in gimbal arrangement.
    d. Magnetization check of spheres and Flinders bar (section 610).
    e. Alignment of compass with fore-and-aft line of ship (section 610).
    f. Alignment of magnets in binnacle.
    g. Alignment of heeling magnet tube under pivot point of compass.
    h. See that corrector magnets are available.

2. Physical checks of gyro, azimuth circle, and peloruses.
    a. Alignment of peloruses with fore-and-aft line of ship (section 610).
    b. Synchronize gyro repeaters with master gyro.
    c. Ensure azimuth circles and peloruses are in good condition.

3. Necessary data.
    a. Past history or log data which might establish length of Flinders bar (sections 610 and 623).
    b. Azimuths for date and observer's position (section 633 and Chapter 17).
    c. Ranges or distant objects in vicinity if needed (local charts).
    d. Correct variation (local charts).
    e. Degaussing coil current settings for swing for residual deviations after adjustment and compensation (ship's Degaussing Folder).

4. Precautions.
    a. Determine transient deviations of compass from gyro repeaters, doors, guns, etc. (sections 636 and 639).
    b. Secure all effective magnetic gear in normal seagoing position before beginning adjustments.
    c. Make sure degaussing coils are secured before beginning adjustments. Use reversal sequence, if necessary.
    d. Whenever possible, correctors should be placed symmetrically with respect to the compass.

5. Adjustments.
    a. Place Flinders bar according to best available information (sections 610, 622 through 625).
    b. Set spheres at mid-position, or as indicated by last deviation table.
    c. Adjust heeling magnet, using balanced dip needle if available (section 637).

B. Adjustments at sea. Make these adjustments with the ship on an even keel and steady on each heading. When

Fore-and-aft and athwartship magnets

Deviation → **Magnets** ↓	Easterly on east *and* westerly on west. (+B error)	Westerly on east *and* easterly on west. (-B error)
No fore and aft magnets in binnacle.	Place magnets red forward.	Place magnets red aft.
Fore and aft magnets red forward.	Raise magnets.	Lower magnets.
Fore and aft magnets red aft.	Lower magnets.	Raise magnets.
Deviation → **Magnets** ↓	Easterly on north and westerly on south. (+C error)	Westerly on north and easterly on south. (-C error)
No athwartship magnets in binnacle.	Place athwartship magnets red starboard.	Place athwartship magnets red port.
Athwartship magnets red starboard.	Raise magnets.	Lower magnets.
Athwartship magnets red port.	Lower magnets.	Raise magnets.

Quadrantial spheres

Deviation → **Spheres** ↓	E. on NE, E. on SE, W. on SW, and W. on NW. (+D error)	W. on NE, E. on SE, W. on SW, andE. on NW. (-D error)
No spheres on binnacle.	Place spheres athwartship.	Place spheres fore and aft.
Spheres at athwartship position.	Move spheres toward compass or use larger spheres.	Move spheres outwards or remove.
Spheres at fore and aft position.	Move spheres outward or remove.	Move spheres toward compass or use larger spheres.
Deviation → **Spheres** ↓	E. on N, W. on E, E. on S, *and* W. on W. (+E error)	W. on N, E. on E, W. on S, *and* E. on W. (-E error)
No spheres on binnacle.	Place spheres at port forward and starboard aft intercardinal positions.	Place spheres at starboard foreward and port aft intercardinal positions.
Spheres at athwartship position.	Slew spheres clockwise through required angle.	Slew spheres counter-clockwise through required angle.
Spheres at fore and aft position.	Slew spheres counter-clockwise through required angle.	Slew spheres clockwise through required angle.

Flinders bar

Deviation change with latitude change → **Bar** ↓	E. on E. and W. on W when sailing toward equator from north latitude or away from equator to south latitude.	W. on E. and E. on W when sailing toward equator from north latitude or away from equator to south latitude.
No bar in holder.	Place required of bar forward.	Place required amount of bar aft.
Bar forward of binnacle.	Increase amount of bar forward.	Deacrease amount of bar forward.
Bar aft of binnacle.	Decrease amount of bar aft.	Increase amount of bar aft.
↑ **Bar** **Deviation change with latitude change** →	W. on E. and E. on W. when sailing toward equator from south latitude or away from equator to north latitude.	E. on E. and W. on W. when sailing toward equator from south latitude or away from equator to south latitude

Heeling magnet
(Adjust with changes in magnetic latitude)

If compass north is attracted to high side of ship when rolling, raise the heeling magnet if red end is up and *lower* the heeling magnet if blue end is up.

If compass north is attracted to low side of ship when rolling, *lower* the heeling magnet if red end is up and *raise* the heeling magnet if blue end is up.

NOTE: Any change in placement of the heeling magnet will affect the deviations on all headings.

Figure 601. Mechanics of magnetic compass adjustment.

using the gyro, swing slowly from heading to heading and check gyro error by sun's azimuth or ranges on each heading to ensure a greater degree of accuracy (section 631). Be sure gyro is set for the mean speed and latitude of the vessel. Note all precautions in section A-4 above. Fly the "OSCAR QUEBEC" international code signal to indicate such work is in progress. Section 631 discusses methods for placing the ship on desired headings.

1. Adjust the heeling magnet while the ship is rolling on north and south magnetic headings until the oscillations of the compass card have been reduced to an average minimum. This step is not required if prior adjustment has been made using a dip needle to indicate proper placement of the heeling magnet.
2. Come to a cardinal magnetic heading, e.g., east (090°). Insert fore-and-aft B magnets, or move the existing B magnets, to remove *all* deviation.
3. Come to a south (180°) magnetic heading. Insert athwartship C magnets, or move the existing C magnets, to remove *all* deviation.
4. Come to a west (270°) magnetic heading. Correct *half* of any observed deviation by moving the B magnets.
5. Come to a north (000°) magnetic heading. Correct *half* of any observed deviation by moving the C magnets.

The cardinal heading adjustments should now be complete.

6. Come to any intercardinal magnetic heading, e.g., northeast (045°). Correct any observed deviation by moving the spheres in or out.
7. Come to the next intercardinal magnetic heading, e.g., southeast (135°). Correct *half* of any observed deviation by moving the spheres.

The intercardinal heading adjustments should now be complete, although more accurate results might be obtained by correcting the D error determined from the deviations on all four intercardinal headings, as discussed in section 615.

8. Secure all correctors before swinging for residual deviations.
9. Swing for residual undegaussed deviations on as many headings as desired, although the eight cardinal and intercardinal headings should be sufficient.
10. Should there still be any large deviations, analyze the deviation curve to determine the necessary corrections and repeat as necessary steps 1 through 9 above.
11. Record deviations and the details of corrector positions on the deviation card to be posted near the compass.

12. Swing for residual degaussed deviations with the degaussing circuits properly energized.
13. Record deviations for degaussed conditions on the deviation card.

The above check-off list describes a simplified method of adjusting compasses, designed to serve as a workable outline for the novice who chooses to follow a step-by-step procedure. The dockside tests and adjustments are essential as a foundation for the adjustments at sea. Neglecting the dockside procedures may lead to spurious results or needless repetition of the procedures at sea. Give careful consideration to these dockside checks prior to making the final adjustment. This will allow time to repair or replace faulty compasses, anneal or replace magnetized spheres or Flinders bars, realign the binnacle, move a gyro repeater if it is affecting the compass, or to make any other necessary preliminary repairs.

Expeditious compass adjustment depends upon the application of the various correctors in a logical sequence so as to achieve the final adjustment with a minimum number of steps. The above check-off list accomplishes this purpose. Figure 607 presents the various compass errors and their correction in condensed form. Frequent, careful observations should be made to determine the constancy of deviations, and results should be systematically recorded. Significant changes in deviation will indicate the need for readjustment.

To avoid Gaussin error (section 636) when adjusting and swinging ship for residuals, the ship should be steady on the desired heading for at least 2 minutes prior to observing the deviation.

602. The Magnetic Compass And Magnetism

The principle of the present day magnetic compass is no different from that of the compasses used by ancient mariners. It consists of a magnetized needle, or an array of needles, allowed to rotate in the horizontal plane. The superiority of the present day compasses over ancient ones results from a better knowledge of the laws of magnetism which govern the behavior of the compass and from greater precision in construction.

Any piece of metal on becoming magnetized will develop regions of concentrated magnetism called **poles**. Any such magnet will have at least two poles of opposite polarity. Magnetic force (flux) lines connect one pole of such a magnet with the other pole. The number of such lines per unit area represents the intensity of the magnetic field in that area. If two such magnetic bars or magnets are placed close to each other, the like poles will repel each other and the unlike poles will attract each other.

Magnetism can be either **permanent** or **induced**. A bar having permanent magnetism will retain its magnetism when it is removed from the magnetizing field. A bar having induced magnetism will lose its magnetism when removed from the magnetizing field. Whether or not a bar will retain its magnetism on removal from the magnetizing field will depend on the strength of that field, the degree of hardness of the iron (retentivity), and also upon the amount of physical stress applied to the bar while in the magnetizing field. The harder the iron, the more permanent will be the magnetism acquired.

603. Terrestrial Magnetism

Consider the earth as a huge magnet surrounded by magnetic flux lines connecting its two **magnetic poles**. These magnetic poles are near, but not coincidental with, the earth's geographic poles. Since the north seeking end of a compass needle is conventionally called the **north pole**, or **positive pole**, it must therefore be attracted to a **south pole**, or **negative pole**.

Figure 603a illustrates the earth and its surrounding magnetic field. The flux lines enter the surface of the earth at different angles to the horizontal, at different magnetic atitudes. This angle is called the **angle of magnetic dip**,

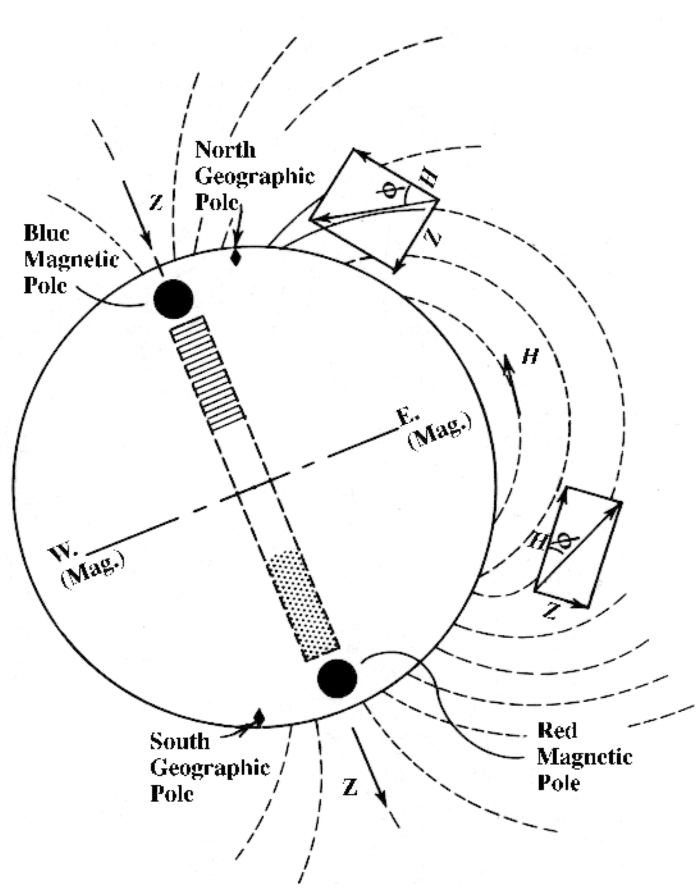


Figure 603aTerrestrial magnetism.

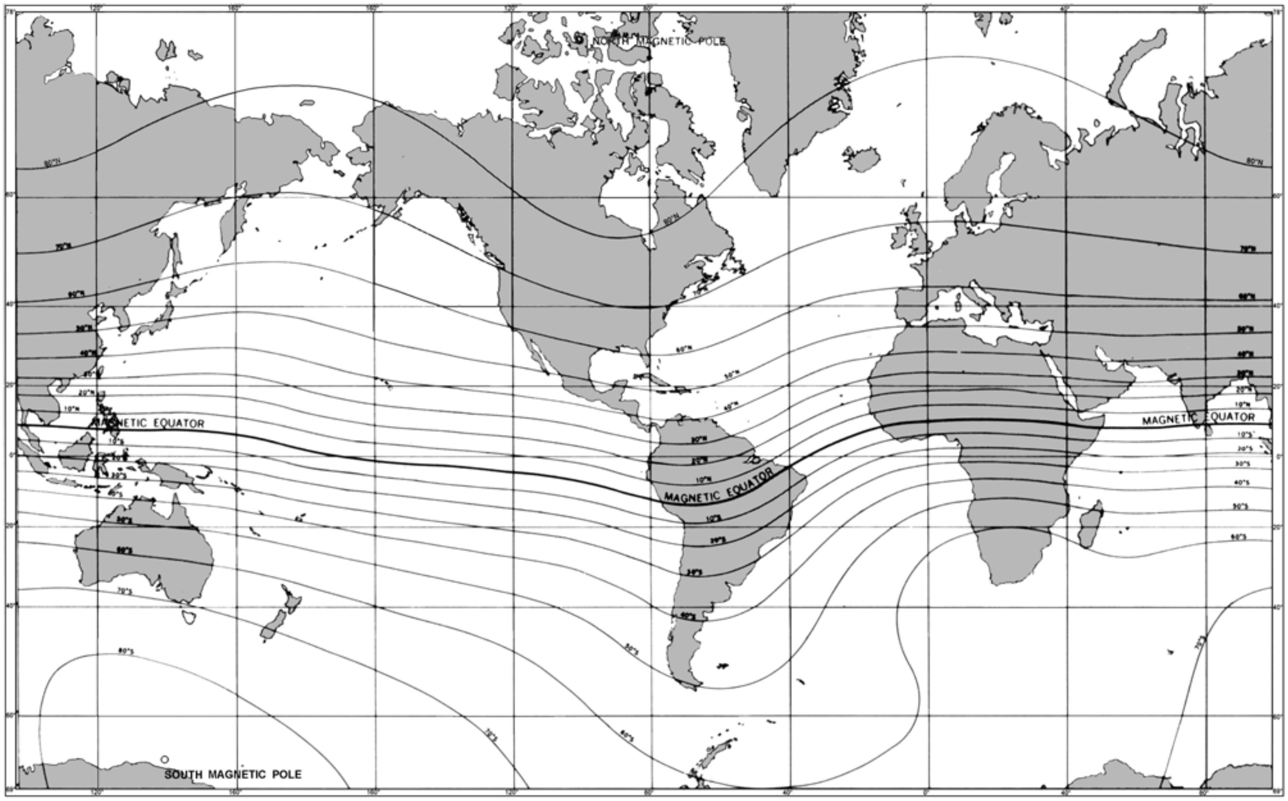


Figure 603b. Magnetic dip chart, a simplification of chart 30.

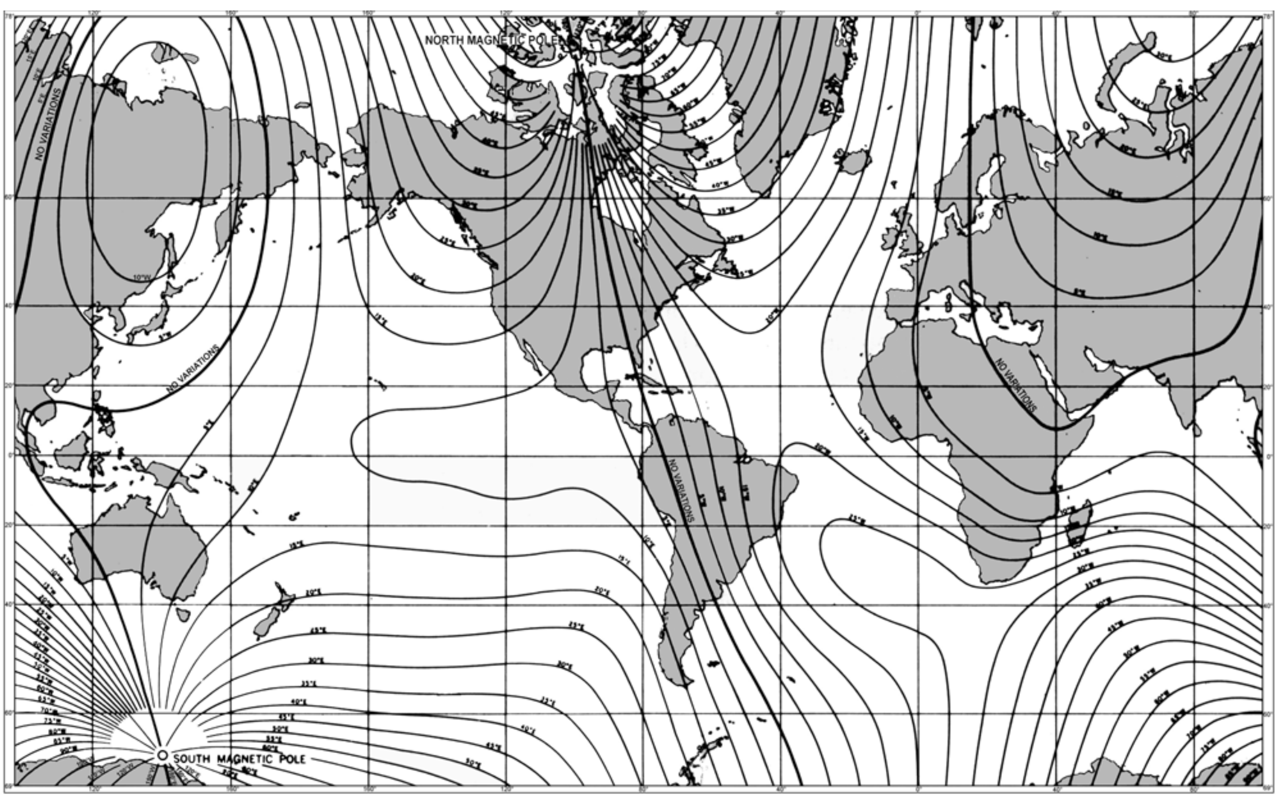


Figure 603c. Magnetic variation chart, a simplification of chart 42.

θ, and increases from 0°, at the magnetic equator, to 90° at the magnetic poles. The total magnetic field is generally considered as having two components: H, the horizontal component; and Z, the vertical component. These components change as the angle θ, changes, such that H is maximum at the magnetic equator and decreases in the direction of either pole; Z is zero at the magnetic equator and increases in the direction of either pole. The values of magnetic dip may be found on **Chart 30** (shown simplified in Figure 603b). The values of H and Z may be found on charts 33 and 36.

Since the magnetic poles of the earth do not coincide with the geographic poles, a compass needle in line with the earth's magnetic field will not indicate true north, but magnetic north. The angular difference between the true meridian (great circle connecting the geographic poles) and the magnetic meridian (direction of the lines of magnetic flux) is called **variation**. This variation has different values at different locations on the earth. These values of magnetic variation may be found on Chart 42 (shown simplified in Figure 603c), on pilot charts, and on the compass rose of navigational charts. The variation for most given areas undergoes an annual change, the amount of which is also noted on charts.

604. Ship's Magnetism

A ship under construction or major repair will acquire permanent magnetism due to hammering and jarring while sitting stationary in the earth's magnetic field. After launching, the ship will lose some of this original magnetism as a result of vibration and pounding in varying magnetic fields, and will eventually reach a more or less stable magnetic condition. The magnetism which remains is the **permanent magnetism** of the ship.

The fact that a ship has permanent magnetism does not mean that it cannot also acquire induced magnetism when placed in the earth's magnetic field. The magnetism induced in any given piece of soft iron is a function of the field intensity, the alignment of the soft iron in that field, and the physical properties and dimensions of the iron. This induced magnetism may add to, or subtract from, the permanent magnetism already present in the ship, depending on how the ship is aligned in the magnetic field. The softer the iron, the more readily it will be magnetized by the earth's magnetic field, and the more readily it will give up its magnetism when removed from that field.

The magnetism in the various structures of a ship, which tends to change as a result of cruising, vibration, or aging, but which does not alter immediately so as to be properly termed induced magnetism, is called **subpermanent magnetism**. This magnetism, at any instant, is part of the ship's permanent magnetism, and consequently must be corrected by permanent magnet correctors. It is the principal cause of deviation changes on a magnetic compass. Subsequent reference to permanent magnetism will refer to the apparent permanent magnetism which includes the existing permanent and subpermanent magnetism.

A ship, then, has a combination of permanent, subpermanent, and induced magnetism. Therefore, the ship's apparent permanent magnetic condition is subject to change from deperming, excessive shocks, welding, and vibration. The ship's induced magnetism will vary with the earth's magnetic field strength and with the alignment of the ship in that field.

605. Magnetic Adjustment

A rod of soft iron, in a plane parallel to the earth's horizontal magnetic field, H, will have a north pole induced in the end toward the north geographic pole and a south pole induced in the end toward the south geographic pole. This same rod in a horizontal plane, but at right angles to the horizontal earth's field, would have no magnetism induced in it, because its alignment in the magnetic field is such that there will be no tendency toward linear magnetization, and the rod is of negligible cross section. Should the rod be aligned in some horizontal direction between those headings which create maximum and zero induction, it would be induced by an amount which is a function of the angle of alignment. If a similar rod is placed in a vertical position in northern latitudes so as to be aligned with the vertical earth's field Z, it will have a south pole induced at the upper end and a north pole induced at the lower end. These polarities of vertical induced magnetization will be reversed in southern latitudes.

The amount of horizontal or vertical induction in such rods, or in ships whose construction is equivalent to combinations of such rods, will vary with the intensity of H and Z, heading and heel of the ship.

The magnetic compass must be corrected for the vessel's permanent and induced magnetism so that its operation approximates that of a completely nonmagnetic vessel. Ship's magnetic conditions create magnetic compass deviations and sectors of sluggishness and unsteadiness. **Deviation** is defined as deflection right or left of the magnetic meridian. Adjusting the compass consists of arranging magnetic and soft iron **correctors** about the binnacle so that their effects are equal and opposite to the effects of the magnetic material in the ship.

The total permanent magnetic field effect at the compass may be broken into three components, mutually 90° apart, as shown in Figure 605a.

The vertical permanent component tilts the compass card, and, when the ship rolls or pitches, causes oscillating deflections of the card. Oscillation effects which accompany roll are maximum on north and south compass headings, and those which accompany pitch are maximum on east and west compass headings.

The horizontal B and C components of permanent magnetism cause varying deviations of the compass as the ship swings in heading on an even keel. Plotting these deviations against compass heading yields the sine and cosine curves shown in Figure 605b. These deviation curves are called semicircular curves because they reverse direction by 180°.

A vector analysis is helpful in determining deviations or

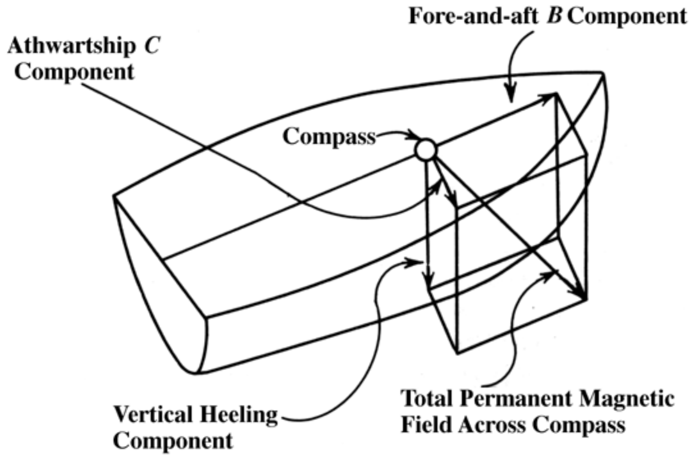


Figure 605a. Components of permanent magnetic field.

the strength of deviating fields. For example, a ship as shown in Figure 605c on an east magnetic heading will subject its compass to a combination of magnetic effects; namely, the earth's horizontal field H, and the deviating field B, at right angles to the field H. The compass needle will align itself in the resultant field which is represented by the vector sum of H and B, as shown. A similar analysis will reveal that the resulting directive force on the compass would be maximum on a north heading and minimum on a south heading because the deviations for both conditions are zero.

The magnitude of the deviation caused by the permanent B magnetic field will vary with different values of H; hence, deviations resulting from permanent magnetic fields will vary with the magnetic latitude of the ship.

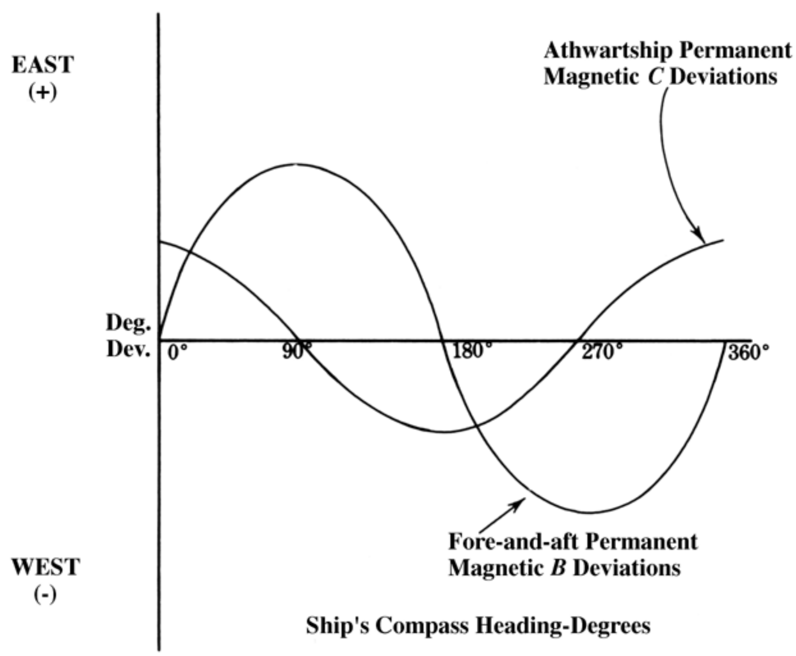


Figure 605b. Permanent magnetic deviation effects.

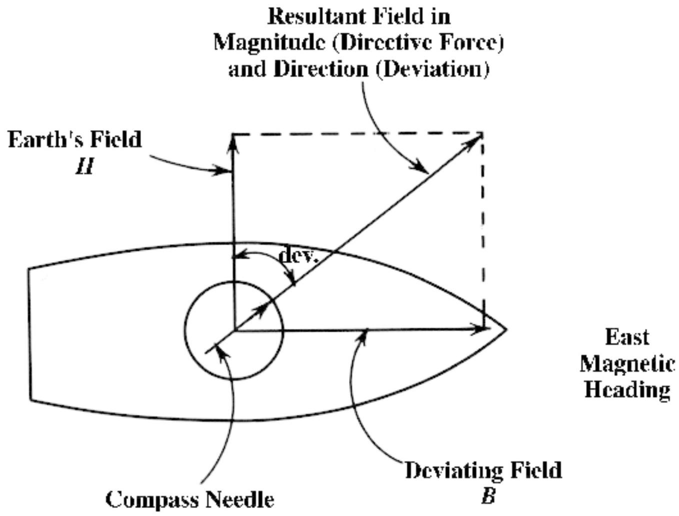


Figure 605c. General force diagram.

606. Induced Magnetism And Its Effects On The Compass

Induced magnetism varies with the strength of the surrounding field, the mass of metal, and the alignment of the metal in the field. Since the intensity of the earth's magnetic field varies over the earth's surface, the induced magnetism in a ship will vary with latitude, heading, and heel of the ship.

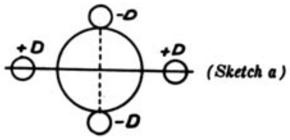
With the ship on an even keel, the resultant vertical induced magnetism, if not directed through the compass itself, will create deviations which plot as a semicircular deviation curve. This is true because the vertical induction changes magnitude and polarity only with magnetic latitude and heel, and not with heading of the ship. Therefore, as long as the ship is in the same magnetic latitude, its vertical induced pole swinging about the compass will produce the same effect on the compass as a permanent pole swinging about the compass.

The earth's field induction in certain other unsymmetrical arrangements of horizontal soft iron create a constant A deviation curve. In addition to this magnetic A error, there are constant A deviations resulting from: (1) physical misalignments of the compass, pelorus, or gyro; (2) errors in calculating the sun's azimuth, observing time, or taking bearings.

The nature, magnitude, and polarity of all these induced effects are dependent upon the disposition of metal, the symmetry or asymmetry of the ship, the location of the binnacle, the strength of the earth's magnetic field, and the angle of dip.

Coefficient	Type deviation curve	Compass headings of maximum deviation	Causes of such errors	Correctors for such errors	Magnetic or compass headings on which to apply correctors
A	Constant.	Same on all.	Human-error in calculations _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ Physical-compass, gyro, pelorus alignment _ _ _ _ _ _ _ _ _ Magnetic-unsymmetrical arrangements of horiz. soft iron.	Check methods and calculations Check alignments Rare arrangement of soft iron rods.	Any.
B	Semicircular $\sin\phi$.	090˚ 270˚	Fore-and-aft component of permanent magnetic field _ _ _ _ _ Induced magnetism in unsymmetrical vertical iron forward or aft of compass.	Fore-and-aft *B* magnets Flinders bar (forward or aft)	090˚ or 270˚.
C	Semicircular $\cos\phi$.	000˚ 180˚	Athwartship component of permanent magnetic field- - - - - - - Induced magnetism in unsymmetrical vertical iron port or starboard of compass.	Athwartship *C* magnets Flinders bar (port or starboard)	000˚ or 180˚.
D	Quadrantral $\sin 2\phi$.	045˚ 135˚ 225˚ 315˚	Induced magnetism in all symmetrical arrangements of horizontal soft iron.	Spheres on appropriate axis. (athwartship for +D) (fore and aft for -D) *See sketch a*	045˚, 135˚, 225˚, or 315˚.
E	Quadrantral $\cos 2\phi$.	000˚ 090˚ 180˚ 270˚	Induced magnetism in all unsymmetrical arrangements of horizontal soft iron.	Spheres on appropriate axis. (port fwd.-stb'd for +E) (stb'd fwd.-port aft for -E) *See sketch b*	000˚, 090˚, 180˚, or 270˚.
Heeling	Oscillations with roll or pitch. Deviations with constant list.	000˚ } roll 180˚ 090˚ } pitch 270˚	Change in the horizontal component of the induced or permanent magnetic fields at the compass due to rolling or pitching of the ship.	Heeling magnet (must be readjusted for latitude changes).	090˚ or 270˚ with dip needle. 000˚ or 180˚ while rolling.

Deviation $= A + B\sin\phi + C\cos\phi + D\sin 2\phi + E\cos 2\phi$ (ϕ = compass heading)



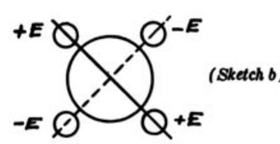


Figure 607. Summary of compass errors and adjustments.

Certain heeling errors, in addition to those resulting from permanent magnetism, are created by the presence of both horizontal and vertical soft iron which experience changing induction as the ship rolls in the earth's magnetic field. This part of the heeling error will naturally change in magnitude with changes of magnetic latitude of the ship. Oscillation effects accompanying roll are maximum on north and south headings, just as with the permanent magnetic heeling errors.

607. Adjustments And Correctors

Since some magnetic effects are functions of the vessel's magnetic latitude and others are not, each individual effect should be corrected independently. Furthermore, to make the corrections, use (1) permanent magnet correctors to compensate for permanent magnetic fields at the compass, and (2) soft iron correctors to compensate for induced magnetism. The compass binnacle provides support for both the compass and such correctors. Typical binnacles hold the following correctors:

1. Vertical permanent **heeling magnet** in the central vertical tube.
2. Fore-and-aft **B permanent magnets** in their trays.
3. Athwartship **C permanent magnets** in their trays.
4. Vertical soft iron **Flinders bar** in its external tube.
5. Soft iron **quadrantal spheres**.

The heeling magnet is the only corrector which corrects for both permanent and induced effects. Therefore, it must be adjusted occasionally for changes in ship's latitude. However, any movement of the heeling magnet will require readjustment of other correctors.

Figure 607 summarizes all the various magnetic conditions in a ship, the types of deviation curves they create, the correctors for each effect, and headings on which each corrector is adjusted. Apply the correctors symmetrically and as far away from the compass as possible. This preserves the uniformity of magnetic fields about the compass needle array.

Fortunately, each magnetic effect has a slightly different characteristic curve. This makes identification and correction convenient. Analyzing a complete deviation curve for its different components allows one to anticipate the necessary corrections.

COMPASS OPERATION

608. Effects Of Errors On The Compass

An uncorrected compass suffers large deviations and sluggish, unsteady operation. These conditions may be associated with the maximum and minimum directive force acting on the compass. The maximum deviation occurs at the point of average directive force; and the zero deviations occur at the points of maximum and minimum directive force.

Applying correctors to reduce compass deviation effects compass error correction. Applying correctors to equalize the directive forces across the compass position could also effect compass correction. The deviation method is most often used because it utilizes the compass itself as the correction indicator. Equalizing the directive forces would require an additional piece of test and calibration equipment.

Occasionally, the permanent magnetic effects at the location of the compass are so large that they overcome the earth's directive force, H. This condition will not only create sluggish and unsteady sectors, but may even freeze the compass to one reading or to one quadrant, regardless of the heading of the ship. Should the compass become so frozen, the polarity of the magnetism which must be attracting the compass needles is indicated; hence, correction may be effected simply by the application of permanent magnet correctors, in suitable quantity to neutralize this magnetism. Whenever such adjustments are made, it would be well to have the ship placed on a heading such that the unfreezing of the compass needles will be immediately evident. For example, a ship whose compass is frozen to a north reading would require fore-and-aft B corrector magnets with the positive ends forward in order to neutralize the existing negative pole which attracted the compass. If made on an east heading, such an adjustment would be practically complete when the compass card was freed to indicate an east heading.

609. Reasons For Correcting Compass

There are several reasons for correcting the errors of the magnetic compass:

1. It is easier to use a magnetic compass if the deviations are small.

2. Even known and compensated for deviation introduces error because the compass operates sluggishly and unsteadily when deviation is present.

3. Even though the deviations are compensated for, they will be subject to appreciable change as a function of heel and magnetic latitude.

Once properly adjusted, the magnetic compass deviations should remain constant until there is some change in the magnetic condition of the vessel resulting from magnetic treatment, shock from gunfire, vibration, repair, or structural changes. Frequently, the movement of nearby guns, doors, gyro repeaters, or cargo affects the compass greatly.

DETAILED PROCEDURES FOR COMPASS ADJUSTMENT

610. Dockside Tests And Adjustments

Section 601, the Adjustment Checkoff List, gives the physical checks required before beginning an adjustment. The adjustment procedure assumes that these checks have been completed. The navigator will avoid much delay by making these checks before starting the magnet and soft iron corrector adjustments. The most important of these checks are discussed below.

Should the compass have a small bubble, add compass fluid through the filling plug on the compass bowl. If an appreciable amount of compass liquid has leaked out, check the sealing gasket and filling plug for leaks.

Take the compass to a place free from all magnetic influences except the earth's magnetic field for tests of **moment** and **sensibility**. These tests involve measurements of the time of vibration and the ability of the compass card to return to a consistent reading after deflection. These tests will indicate the condition of the pivot, jewel, and magnetic strength of the compass needles.

Next, check the spheres and Flinders bar for residual magnetism. Move the spheres as close to the compass as possible and slowly rotate each sphere separately. Any appreciable deflection (2° or more) of the compass needles resulting from this rotation indicates residual magnetism in the spheres. The Flinders bar magnetization check is preferably made with the ship on an east or west compass heading. To make this check: (a) note the compass reading with the Flinders bar in the holder; (b) invert the Flinders bar in the holder and again note the compass reading. Any appreciable difference (2° or more) between these observed readings indicates residual magnetism in the Flinders bar. Spheres or Flinders bars which show signs of such residual magnetism should be **annealed**, i.e., heated to a dull red and allowed to cool slowly.

Correct alignment of the lubber's line of the compass, gyro repeater, and pelorus with the fore-and-aft line of the ship is important. Any misalignment will produce a constant error in the deviation curve. All of these instruments may be aligned correctly with the fore-and-aft line of the ship by using the azimuth circle and a metal tape measure. Should the instrument be located on the centerline of the ship, a sight is taken on a mast or other object on the centerline. If the instrument is not on the centerline, measure the distance from the centerline of the ship to the center of the instrument. Mark this distance off from the centerline forward or abaft the compass and place reference marks on the deck. Take sights on these marks.

Align the compass so that the compass' lubber's line is parallel to the fore-and-aft line of the ship. Steering compasses may occasionally be deliberately misaligned in order to correct for any magnetic A error present, as discussed in section 611.

Adjust the Flinders bar first because it is subject to induction from several of the correctors and its adjustment is not dependent on any single observation. To adjust the Flinders bar, use one of the following methods:

1. Use deviation data obtained at two different magnetic latitudes to calculate the proper length of Flinders bar for any particular compass location. Sections 622 through 624 contain details on acquiring the data and making the required calculations.

2. If the above method is impractical, set the Flinders bar length by:

    a. Using a Flinders bar length determined by other ships of similar structure.

    b. Studying the arrangement of masts, stacks, and other vertical structures and estimating the Flinders bar length required.

If these methods are not suitable, omit the Flinders bar until the required data are acquired.

The iron sections of Flinders bar should be continuous and placed at the top of the tube with the longest section at the top. Wooden spacers are used at the bottom of the tube.

Having adjusted the length of Flinders bar, place the spheres on the bracket arms at an approximate position. If the compass has been adjusted previously, place the spheres at the position indicated by the previous deviation table. In the event the compass has never been adjusted, place the spheres at the midpoint on the bracket arms.

The next adjustment is the positioning of the heeling magnet using a properly balanced dip needle. Section 637 discusses this procedure.

These three dockside adjustments (Flinders bar, quadrantal spheres, and heeling magnet) will properly establish the conditions of mutual induction and shielding of the compass. This minimizes the steps required at sea to complete the adjustment.

611. Expected Errors

Figure 607 lists six different coefficients or types of deviation errors with their causes and corresponding correctors. A discussion of these coefficients follows:

The **A error** is caused by the miscalculation of azimuths or by physical misalignments rather than magnetic effects of unsymmetrical arrangements of horizontal soft iron. Thus,

checking the physical alignments at dockside and making careful calculations will minimize the A error. Where an azimuth or bearing circle is used on a standard compass to determine deviations, any observed A error will be solely magnetic A error because such readings are taken on the face of the compass card rather than at the lubber's line of the compass. On a steering compass where deviations are obtained by a comparison of the compass lubber's line reading with the ship's magnetic heading, as determined by pelorus or gyro, any observed A error may be a combination of magnetic A and mechanical A (misalignment). These facts explain the procedure in which only mechanical A is corrected on the standard compass, by realignment of the binnacle, and both mechanical A and magnetic A errors are corrected on the steering compass by realignment of the binnacle. On the standard compass, the mechanical A error may be isolated from the magnetic A error by making the following observations simultaneously:

1. Record a curve of deviations by using an azimuth (or bearing) circle. Any A error found will be solely magnetic A.

2. Record a curve of deviations by comparison of the compass lubber's line reading with the ship's magnetic heading as determined by pelorus or by gyro. Any A error found will be a combination of mechanical A and magnetic A.

3. The mechanical A on the standard compass is then found by subtracting the A found in the first instance from the total A found in the second instance, and is corrected by rotating the binnacle in the proper direction by that amount. It is neither convenient nor necessary to isolate the two types of A on the steering compass and all A found by using the pelorus or gyro may be removed by rotating the binnacle in the proper direction.

The **B error** results from both the fore-and-aft permanent magnetic field across the compass and a resultant unsymmetrical vertical induced effect forward or aft of the compass. The former is corrected by the use of fore-and-aft B magnets, and the latter is corrected by the use of the Flinders bar forward or aft of the compass. Because the Flinders bar setting is a dockside adjustment, any remaining B error is corrected by the use of fore-and-aft B magnets.

The **C error** results from the athwartship permanent magnetic field across the compass and a resultant unsymmetrical vertical induced effect athwartship of the compass. The former is corrected by the use of athwartship C magnets, and the latter by the use of the Flinders bar to port or starboard of the compass. Because the vertical induced effect is very rare, the C error is corrected by athwartship C magnets only.

The **D error** is due only to induction in the symmetrical arrangements of horizontal soft iron, and requires correction by spheres, generally athwartship of the compass.

E error of appreciable magnitude is rare, since it is caused by induction in the unsymmetrical arrangements of horizontal soft iron. When this error is appreciable it may be corrected by slewing the spheres, as described in section 620.

As stated previously, the heeling error is adjusted at dockside with a **balanced dip needle** (see section 637).

As the above discussion points out, certain errors are rare and others are corrected at dockside. Therefore, for most ships, only the B, C, and D errors require at sea correction. These errors are corrected by the fore-and-aft B magnets, athwartship C magnets, and quadrantal spheres respectively.

612. Study Of Adjustment Procedure

Inspecting the B, C, and D errors pictured in Figure 612a demonstrates a definite isolation of deviation effects on *cardinal* compass headings.

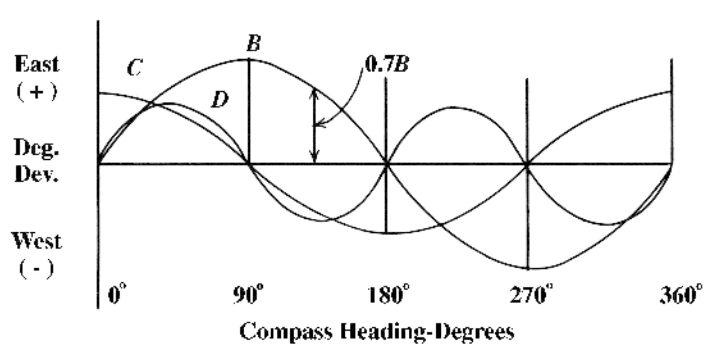


Figure 612a. B, C, and D deviation effects.

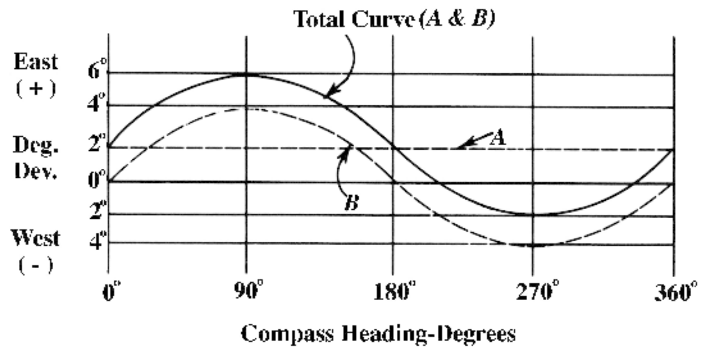


Figure 612b. A and B deviation.

For example, on 090° or 270° compass headings, the only deviation which is effective is that due to B. This isolation, and the fact that the B effect is greatest on these two headings, make these headings convenient for B correction. Correction of the B deviation on a 090° heading will correct the B deviation on the 270° heading by the same amount but in the opposite direction and naturally, it will not change the deviations on the 000° and 180° headings, except where B errors are large. However, the total deviation on all the intercardinal headings will be shifted in the same direction as the adjacent 090° or 270° deviation correction, but only by seven-tenths (0.7) of that amount, since the sine of 45° equals 0.707. The same convenient isolation of effects and corrections of C error will also change the deviations on all the intercardinal headings by the seven-tenths rule.

Note that only after correcting the B and C errors on the cardinal headings, and consequently their proportional values of the total curve on the intercardinal headings, can the D error be observed separately on any of the intercardinal headings. The D error may then be corrected by use of the spheres on any intercardinal heading. Correcting D error will, as a rule, change the deviations on the intercardinal headings only, and not on the cardinal headings. Only when the D error is excessive, the spheres are magnetized, or the permanent magnet correctors are so close as to create excessive induction in the spheres will there be a change in the deviations on cardinal headings as a result of sphere adjustments. Although sphere correction does not generally correct deviations on cardinal headings, it does improve compass stability on these headings.

If it were not for the occasional A or E errors, adjusting observed deviations to zero on two adjacent cardinal headings and then on the intermediate intercardinal heading would be sufficient. However, Figure 612b, showing a combination of A and B errors, illustrates why the adjusting procedure must include correcting deviations on more than the three essential headings.

Assuming no A error existed in the curve illustrated in Figure 612b, and the total deviation of 6° E on the 090° heading were corrected with B magnets, the error on the 270° heading would be 4° E due to B overcorrection. If this 4° E error were taken out on the 270° heading, the error on the 090° heading would then be 4° E due to B undercorrection. To eliminate this endlessly iterative process and correct the B error to the best possible flat curve, split this 4° E difference, leaving 2° E deviation on each opposite heading. This would, in effect correct the B error, leaving only the A error of 2° E which must be corrected by other means. It is for this reason that, (1) splitting is done between the errors noted on opposite headings, and (2) good adjustments entail checking on all headings rather than on the fundamental three.

613. Adjustment Procedures At Sea

Before proceeding with the adjustment at sea the following precautions should be observed:

1. Secure all effective magnetic gear in the normal seagoing position.

2. Make sure the degaussing coils are secured, using the reversal sequence, if necessary (See section 643).

The adjustments are made with the ship on an even keel, swinging from heading to heading slowly, and after steadying on each heading for at least 2 minutes to avoid Gaussin error.

Most adjustments can be made by trial and error, or by routine procedure such as the one presented in section 601. However, the procedures presented below provide analytical methods in which the adjuster is always aware of the errors' magnitude on all headings as a result of his movement of the different correctors.

Analysis Method. A complete deviation curve can be taken for any given condition, and an estimate made of all the approximate coefficients. See section 615. From this estimate, the approximate coefficients are established and the appropriate corrections are made with reasonable accuracy on a minimum number of headings. If the original deviation curve has deviations greater than 20°, rough adjustments should be made on two adjacent cardinal headings before recording curve data for such analysis. The mechanics of

Heading by compass	1 Original deviation curve	2 Anticipated curve after first correcting A = 1.0° E	3 Anticipated curve after next correcting B = 12.0° E	4 Anticipated curve after next correcting C = 8.0° E	5 Anticipated curve after next correcting D = 5.0° E	6 Anticipated curve after next correcting E = 1.5° E
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	10.5 E.	9.5 E.	9.5 E.	1.5 E.	1.5 E.	0.0
045	20.0 E.	19.0 E.	10.6 E.	5.0 E.	0.0	0.0
090	11.5 E.	10.5 E.	1.5 W.	1.5 W.	1.5 W.	0.0
135	1.2 W.	2.2 W.	10.6 W.	5.0 W.	0.0	0.0
180	5.5 W.	6.5 W.	6.5 W.	1.5 E.	1.5 E.	0.0
225	8.0 W.	9.0 W.	0.6 W.	5.0 E.	0.0	0.0
270	12.5 W.	13.5 W.	1.5 W.	1.5 W.	1.5 W.	0.0
315	6.8 W.	7.8 W.	0.6 E.	5.0 W.	0.0	0.0

Figure 613a. Tabulating anticipated deviations.

applying correctors are presented in Figure 601. A method of tabulating the anticipated deviations after each correction is illustrated in Figure 613a. The deviation curve used for illustration is the one which is analyzed in section 615. Analysis revealed these coefficients:

A = 1.0˚ E
B = 12.0˚ E
C = 8.0˚ E
D = 5.0˚ E
E = 1.5˚ E

One-Swing Method. More often it is desirable to begin adjustment immediately, eliminating the original swing for deviations and the estimate of approximate coefficients. In this case the above problem would be solved by tabulating data and anticipating deviation changes as the corrections are made. Figure 613b illustrates this procedure. Note that a new column of values is started after each change is made. This method of tabulation enables the adjuster to calculate the new residual deviations each time a corrector is changed, so that a record of deviations is available at all times during the swing. Arrows indicate where each change is made.

Since the B error is generally greatest, it is corrected first. Therefore, on a 090° heading the 11.5° E deviation is corrected to approximately zero by using fore-and-aft B magnets. A lot of time need not be spent trying to reduce this deviation to exactly zero since the B coefficient may not be exactly 11.5° E, and some splitting might be desirable later. After correcting on the 090° heading, the swing would then be continued to 135° where a 9.2° W error would be observed. This deviation is recorded, but no correction is made because the quadrant error is best corrected after the deviations on all four cardinal headings have been corrected. The deviation on the 180° heading would be observed as 5.5° W. Since this deviation is not too large and splitting may be necessary later, it need not be corrected at this time. Continuing the swing to 225° a 0.0° deviation would be observed and recorded. On the 270° heading the observed error would be 1.0° W, which is compared with 0.0° deviation on the opposite 090° heading. This could be split, leaving 0.5° W deviation on both 090° and 270°, but since this is so small it may be left uncorrected. On 315˚ the observed deviation would be 1.2° E. At 000° a deviation of 10.5° E would be observed and compared with 5.5° W on 180°. Analysis of the deviations on 000° and 180° headings reveals an 8.0° E, C error, which should then be corrected with athwartship C magnets leaving 2.5° E deviation on both the 000° and 180° headings.

Heading	First observation	Observed deviations after correcting B = 11.5° E	Anticipated deviations after correcting C = 8.0° E	Anticipated deviations after correcting D =5.0° E	Anticipated deviations after correcting A = 1.0° E	Anticipated deviations after correcting E = 1.5° E
Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
000	...	10.5 E.→	2.5 E.	2.5 E.	1.5 E.	0.0
045	...	...	6.4 E.→	1.4 E.→	0.4 E.	0.4 E.
090	11.5 E.→	0.0	0.0	0.0	1.0 W.→	0.5 E.
135	...	9.2 W.	3.6 W.	1.4 E.	0.4 E.	0.4 E.
180	...	5.5 W.	2.5 E.	2.5 E.	1.5 E.	0.0
225	...	0.0	5.6 E.	0.6 E.	0.4 W.	0.4 W.
270	...	1.0 W.	1.0 W.	1.0 W.	2.0 W.	0.5 W.
315	...	1.2 E.	4.4 W.	0.6 E.	0.4 W.	0.4 W.

Figure 613b. Tabulating anticipated deviations by the one-swing.

All the deviations in column two are now recalculated on the basis of such an adjustment at 000° heading and entered in column three. Continuing the swing, the deviation on 045° would then be noted as 6.4° E. Knowing the deviations on all intercardinal headings, it is now possible to estimate the approximate coefficient D. D is 5.0° E so the 6.4° E deviation on 045° is corrected to 1.4° E and new anticipated values are recorded in another column. This anticipates a fairly good curve, an estimate of which reveals, in addition to the B of 0.5° E which was not considered large enough to warrant correction, an A of 1.0° E and an E of 1.5° E. These A and E errors may or may not be corrected, as practical. If they are corrected, the subsequent steps would be as indicated in the last two columns. Now the ship has made only one swing, all corrections have been made, and some idea of the expected curve is available.

614. Deviation Curves

The last step, after completion of either of the above methods of adjustment, is to secure all correctors in position and to swing for residual deviations. These residual deviations are for undegaussed conditions of the ship, which should be recorded together with details of corrector positions. Figure 614 illustrates both sides of NAVSEA 3120/4 with proper instructions and sample deviation and Flinders bar data. Should the ship be equipped with degaussing coils, a swing for residual deviations under degaussed conditions should also be made and data recorded on NAVSEA 3120/4.

On these swings, exercise extreme care in taking bearings or azimuths and in steadying down on each heading since this swing is the basis of standard data for the particular compass. If there are any peculiar changeable errors, such as movable guns, listing of the ship, or anticipated decay from deperming, which would effect the reliability of the compass, they should also be noted on the deviation card at this time. Section 639 discusses these many sources of error in detail.

If the Flinders bar adjustment is not based on accurate

MAGNETIC COMPASS TABLE NAVSEA RPT. 3530-2
NAVSEA 3120/4 (REV. 6-72) (FRONT) *(Formerly NAVSHIPS 1104)*
S/N 0105-601-9521

U.S.S. ______ NO. ______ *(BB, CL, DD, etc.)*

[X] PILOT HOUSE [ ] SECONDARY CONNING STATION [ ] OTHER ______

BINNACLE TYPE [X] NAVY ST'D [ ] OTHER ______

COMPASS 7-1/2 MAKE C.G. Conn SERIAL NO. 8560

TYPE CC COILS "K" DATE 9 September 1975

READ INSTRUCTIONS ON BACK BEFORE STARTING ADJUSTMENT

SHIPS HEAD MAGNETIC	DEVIATIONS DG OFF	DEVIATIONS DG ON	SHIPS HEAD MAGNETIC	DEVIATIONS DG OFF	DEVIATIONS DG ON
0	0.5E	0.5E	180	0.5W	0.0
15	1.0E	1.0E	195	1.0W	0.5W
30	1.5E	1.5E	210	1.0W	1.0W
45	2.0E	1.5E	225	1.5W	1.5W
60	2.0E	2.0E	240	2.0W	2.0W
75	2.5E	2.5E	255	2.0W	2.5W
90	2.5E	3.0E	270	1.5W	2.0W
105	2.0E	2.5E	285	1.0W	1.5W
120	1.5E	2.0E	300	1.0W	1.0W
135	1.5E	1.5E	315	0.5W	0.5W
150	1.0E	1.0E	330	0.5W	0.5W
165	0.0	0.5E	345	0.0	0.0

DEVIATIONS DETERMINED BY: [ ] SUN'S AZIMUTH [X] GYRO [ ] SHORE BEARINGS

B 6 MAGNETS RED [ ] FORE [X] AFT AT 12" FROM COMPASS CARD

C 4 MAGNETS RED [ ] PORT [X] STBD AT 6" FROM COMPASS CARD

D 2-7" [X] SPHERES [ ] CYLS AT 12" [X] ATHWARTSHIP [ ] SLEWED - ° [ ] CLOCKWISE [ ] CTR. CLOCKWISE

HEELING MAGNET: [ ] RED UP [X] BLUE UP 6" FROM COMPASS CARD FLINDERS BAR: [X] FORE [ ] AFT 12"

[X] LAT 18°00'N [X] LONG 120°00'E
[ ] H 0.385 [ ] Z 0.151

SIGNED *(Adjuster or Navigator)* APPROVED *(Commanding)*

VERTICAL INDUCTION DATA
(Fill out completely before adjusting)

RECORD DEVIATION ON AT LEAST TWO ADJACENT CARDINAL HEADINGS

BEFORE STATING ADJUSTMENT: N 8 W ; E 0 ; S 4 E ; W 9 E .

RECORD BELOW INFORMATION FROM LAST NAVSHIPS 3120/4 DEVIATION TABLE:

DATE 5 December 1974 [ ] LAT 32 53N [ ] LONG 117 18W
[ ] H .260 [ ] Z .420

12" FLINDERS BAR [X] FORWARD [ ] AFT DEVIATIONS N 2.5W E 7E ; S 6.5E W 5W .

RECORD HERE DATA ON RECENT OVERHAULS, GUNFIRE, STRUCTURAL CHANGES, FLASHING, DEPERMING, WITH DATES AND EFFECT ON MAGNETIC COMPASSES

Shipyard overhaul:
3 Oct - 2 Dec 1974
Depermed at Norfolk, Va.:
3 Dec 1974

PERFORMANCE DATA

COMPASS AT SEA: [ ] UNSTEADY [X] STEADY
COMPASS ACTION: [ ] SLOW [X] SATISFACTORY
NORMAL DEVIATIONS: [X] CHANGE [ ] REMAIN RELIABLE
DEGAUSSED DEVIATIONS: [X] VARY [ ] DO NOT VARY

REMARKS

INSTRUCTIONS

1. This form shall be filled out by the Navigator for each magnetic compass as set forth in Chapter 9240 of NAVAL SHIPS TECHNICAL MANUAL.
2. When a swing for deviations is made, the deviations should be recorded both with degaussing coils off and with degaussing coils energized at the proper currents for heading and magnetic zone.
3. Each time this form is filled out after a swing for deviations, a copy shall be submitted to: Naval Ship Engineering Center Hyattsville, Maryland 20782. A letter of transmittal is not required.
4. When choice of box is given, check applicable box.
5. Before adjusting, fill in section on "Vertical Induction Data" above.

NAVSEA 3120/4 (REV. 6-72) (REVERSE) C-[illegible]

Figure 614. Deviation table, NAVSEA 3120/4.

data, as with a new ship, exercise particular care in recording the conventional Daily Compass Log data during the first cruise on which a considerable change of magnetic latitude occurs.

In order to have a reliable and up-to-date deviation card at all times, swing the ship to check compass deviations and to make readjustments, after:

1. Radical changes in magnetic latitude.
2. Deperming. (Delay adjustment for several days after treatment.)
3. Structural changes.
4. Long cruises or docking on the same heading, causing the permanent magnetic condition of the vessels to change.
5. Altering magnetic equipment near the binnacle.
6. Reaching the magnetic equator to acquire Flinders bar data.
7. At least once annually.
8. Changing the heeling magnet position, if Flinders bar is present.
9. Readjusting any corrector.
10. Changing magnetic cargo.
11. Commissioning.

DEVIATION CURVES AND THE ESTIMATION OF APPROXIMATE COEFFICIENTS

615. Simple Analysis

The data for the deviation curve illustrated in Figure 615 is listed below:

	Ship's Compass Heading	*Total Deviation*
N	000 °	10.5 ° E
NE	045 °	20.0 ° E
E	090 °	11.5 ° E
SE	135 °	1.2 ° W
S	180 °	5.5 ° W
SW	225 °	8.0 ° W
W	270 °	12.5 ° W
NW	315 °	6.8 ° W

Since A is the coefficient of constant deviation, its approximate value is obtained from the above data by estimating the mean of the algebraic sum of all the deviations. Throughout these computations the sign of east deviation is considered plus, and west deviation is considered minus.

$$8A = +10.5^\circ+20.0^\circ+11.5^\circ- 1.2^\circ-5.5^\circ- 8.0^\circ- 12.5^\circ- 6.8^\circ$$
$$8A = +42.0^\circ - 34.0^\circ$$
$$8A = +8.0^\circ$$
$$A = +1.0^\circ\ (1.0^\circ\ E)$$

Since B is the coefficient of semicircular sine deviation,

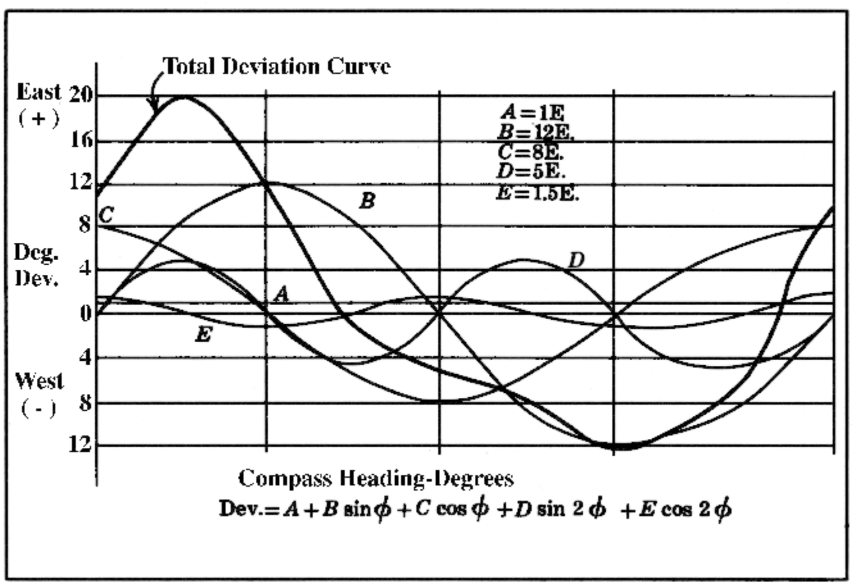


Figure 615. Example of typical deviation curve and its components.

its value is maximum, but of opposite polarity, on 090° and 270° headings. The approximate B coefficient is estimated by taking the mean of the deviations at 090° and 270° with the sign at 270° reversed.

$$2B = +11.5^\circ\ (+12.5^\circ)$$
$$2B = +24.0^\circ$$
$$B = +12.0^\circ\ (12.0^\circ\ E)$$

Similarly, since C is the coefficient of semicircular cosine deviation, its value is maximum, but of opposite polarity, on 000° and 180° headings; and the approximate C coefficient is estimated by taking the mean of the deviations at 000° and 180° with the sign at 180° reversed.

$$2C = +10.5^\circ + (+5.5^\circ)$$
$$2C = +16.0^\circ$$
$$C = +8.0^\circ\ (8.0^\circ\ E)$$

D is the coefficient of quadrantal sine deviation having maximum, but alternately opposite, polarity on the intercardinal headings. Hence, the approximate D coefficient is estimated by taking the mean of the four intercardinal deviations with the signs at 135° and 315° reversed.

$$4D = (+20.0^\circ) + (+1.2^\circ) + (-8.0^\circ) + (+6.8^\circ)$$
$$4D = +20.0^\circ$$
$$D = +5.0^\circ\ (5.0^\circ\ E)$$

E is the coefficient of quadrantal cosine deviation having maximum, but alternately opposite, polarity on the cardinal headings. Therefore, the approximate E coefficient is estimated by taking the mean of the four cardinal deviations with the signs at 090˚ and 270˚ reversed.

$$4E = (+10.5^\circ) + (-11.5^\circ) + (-5.5^\circ) + (+12.5^\circ)$$
$$4E = +6.0^\circ$$
$$E = +1.5^\circ\ (1.5^\circ\ E)$$

These approximate coefficients are estimated from deviations on compass headings rather than on magnetic headings. The arithmetical solution of such coefficients will automatically assign the proper polarity to each coefficient.

Summarizing the above we find the approximate coefficients of the given deviation curve to be:

$$A = 1.0^\circ\ E$$
$$B = 12.0^\circ\ E$$
$$C = 8.0^\circ\ E$$
$$D = 5.0^\circ\ E$$
$$E = 1.5^\circ\ E$$

Each of these coefficients represents a component of deviation which can be plotted as shown in Figure 615. The polarity of each component in the first quadrant must agree with the polarity of the coefficient. A check on the components in Figure 615 will reveal that their summation equals the original curve.

This method of analysis is accurate only when the deviations are less than 20°. The mathematical expression for the deviation on any heading, using the approximate coefficients, is:

$$\text{Deviation} = A + B \sin\theta + C \cos\theta + D \sin 2\theta + E \cos 2\theta$$

(where θ represents compass heading).

The directions given above for calculating coefficients A and B are not based upon accepted *theoretical* methods of estimation. Some cases may exist where appreciable differences may occur in the coefficients as calculated by the above method and the accepted theoretical method. The proper calculation of coefficients B and C is as follows:

Letting D1, D2, . . ., D8 be the eight deviation data, then

$$B = \frac{\sqrt{2}}{8}\left(D_2 + D_4 - D_6 - D_8 + \frac{1}{4}(D_3 - D_7)\right)$$

$$C = \frac{\sqrt{2}}{8}\left(D_2 - D_4 - D_6 + D_8 + \frac{1}{4}(D_1 - D_5)\right)$$

Substituting deviation data algebraically, east being plus and west minus,

$$B = \frac{\sqrt{2}}{8}\left(20.0 - 1.2 - 8.0 - 6.8 + \frac{1}{4}(11.5 - 12.5)\right)$$

$$B = +12$$

$$C = \frac{\sqrt{2}}{8}\left(20.0 - 1.2 - 8.0 + 6.8 + \frac{1}{4}(10.5 - 5.5)\right)$$

$$C = +8$$

This method of estimating approximate coefficients is convenient for:

1. Analyzing an original deviation curve in order to anticipate necessary corrections.
2. Analyzing a final deviation curve for the determination of additional refinements.
3. Simplifying the actual adjustment procedure by anticipating effects of certain corrector changes on the deviations at all other headings.

616. Approximate And Exact Coefficients

The above estimations are for the approximate coefficients and not for exact coefficients. Approximate coefficients are in terms of angular deviations which are caused by certain magnetic forces, and some of these deviations are subject to change with changes in the

directive force, H. The exact coefficients are expressions of magnetic forces, dealing with: (a) arrangements of soft iron, (b) components of permanent magnetic fields, (c) components of the earth's magnetic field, and (d) the shielding factor. Thus, the exact coefficients are expressions of magnetic force which produce the deviations expressed by the approximate coefficients. The exact coefficients are for mathematical considerations while the approximate coefficients are more practical for adjustment purposes. For this reason, the exact coefficients, and the associated mathematics, are not expanded further in this text.

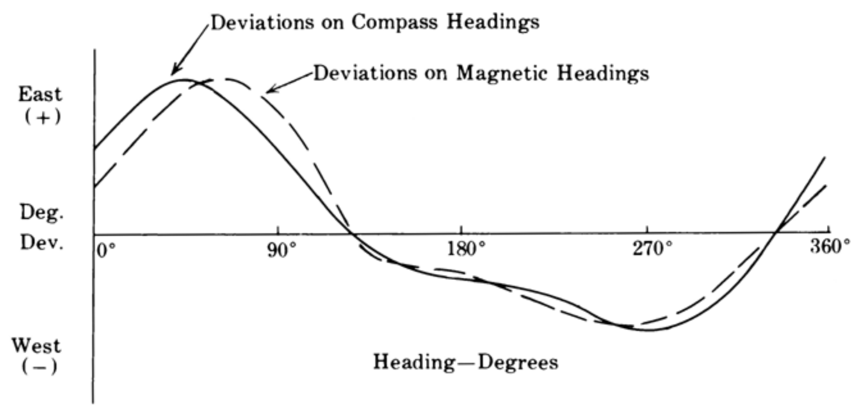


Figure 617. Comparison of deviation curves (magnetic heading versus compass heading).

CORRECTOR EFFECTS

617. Compass Heading And Magnetic Heading

When deviations are large, there is an appreciable difference in the deviation curve if it is plotted on cross-section paper against compass headings or against magnetic headings of the ship. Not only is there a difference in the shape of the curves, but if only one curve is available, navigators will find it difficult in applying deviations when converting between magnetic and compass headings. When deviations are small, no conversion is necessary. Figure 617 illustrates the differences mentioned above by presenting the deviation values used in Figure 617 plotted against both magnetic and compass headings.

618. Understanding Interactions Between Correctors

Until now the principles of compass adjustment have been considered from a qualitative point of view. In general this is quite sufficient since the correctors need merely be moved until the desired amount of correction is obtained. However, it is often valuable to know the quantitative effects of different correctors as well as their qualitative effects. All the correctors are not completely independent of each other. Interaction results from the proximity of the permanent magnet correctors to the soft iron correctors. Consequently any shift in the relative position of the various correctors will change their interactive as well as their separate correction effects. Additional inductions exist in the soft iron correctors from the magnetic needles of the compass itself. The adjuster should be familiar with the nature of these interactions.

619. Quandrantal Sphere Correction

Figure 619 presents the approximate quadrantal correction available with different sizes of spheres, at various positions on the sphere brackets, and with different magnetic moment compasses. These quadrantal corrections apply whether the spheres are used as D, E, or combination D and E correctors. Quadrantal correction from spheres is due partially to the earth's field induction and partially to compass needle induction. Since compass needle induction does not change with magnetic latitude but earth's field induction does, the sphere correction is not constant for all magnetic latitudes. A reduction in the percentage of needle induction in the spheres to the earth's field induction in the spheres will improve the constancy of sphere correction over all magnetic latitudes. Such a reduction in the percentage of needle induction may be obtained by:

1. Utilizing a low magnetic moment compass.
2. Utilizing special spheroidal-shaped correctors,

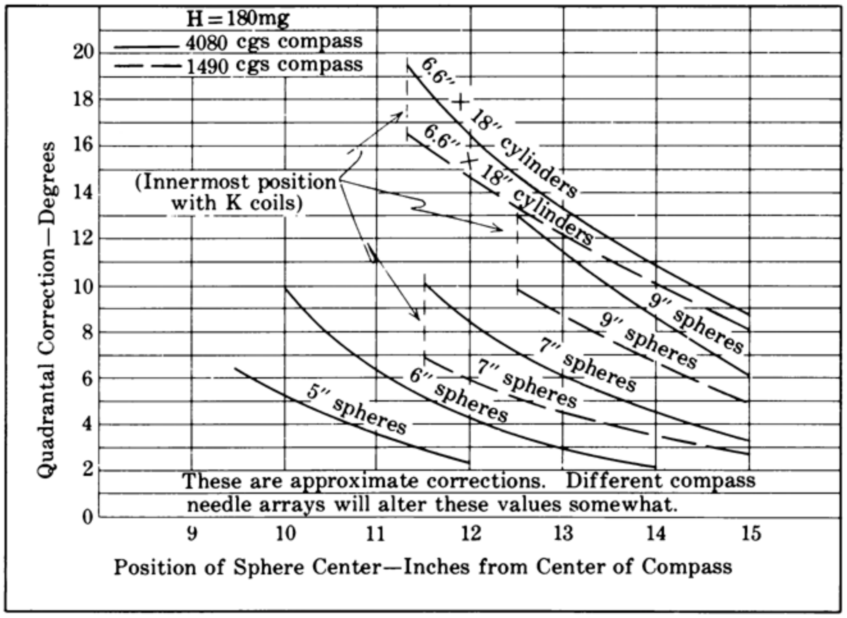


Figure 619. Quandrantal correction curves.

placed with their major axes perpendicular to their axis of position.

3. Using larger spheres farther away from the compass.

620. Slewing Of Spheres

Figure 620 shows a chart for determining the proper slewed position for spheres. The total values of the D and E quadrantal coefficients are used on the chart to locate a point of intersection. This point directly locates the angle and direction of slew for the spheres on the illustrated binnacle. This point will also indicate, on the radial scale, the resultant amount of quadrantal correction required from the spheres in the new slewed position to correct for both D and E coefficients. The total D and E coefficients may be calculated by an analysis of deviations on the uncorrected binnacle, or by summarizing the uncorrected coefficients with those already corrected. The data in Figure 619 and 622 will be useful in either procedure.

Example: A ship having a Navy Standard binnacle, with 7" spheres at 13" position athwartship, and a 12" Flinders bar forward, is being swung for adjustment. It is observed that 4° E D error and 6° E E error exist with the spheres in position. Since the spheres are athwartship, the

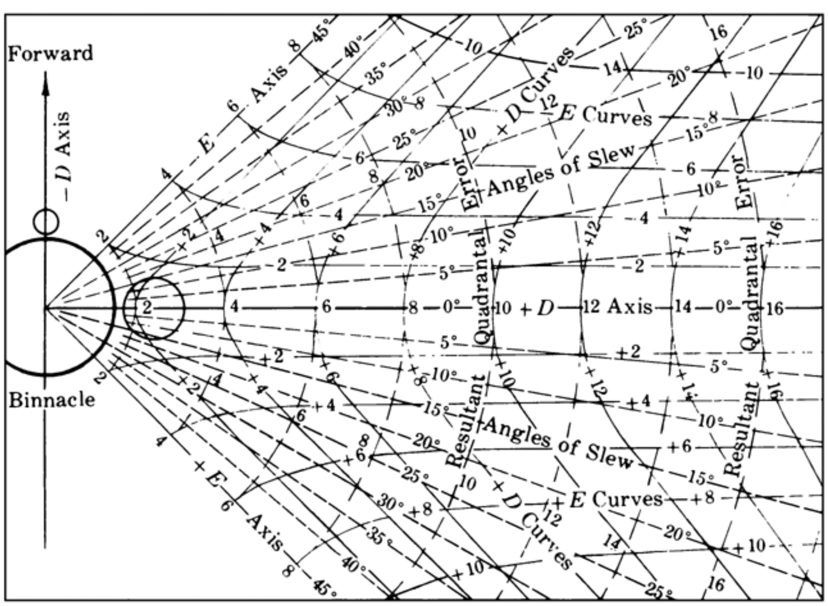


Figure 620. Slewing of quandrantal spheres.

total E coefficient for the ship is 6° E, as observed. Figure 619 indicates that the spheres in their present position are correcting 6° E D error, hence the total D coefficient of the ship and Flinders bar is 10° E. Figure 620 indicates that 6° E E and 10° E D coefficients require slewing the spheres 15.5° clockwise from their present athwartship position. The resultant quadrantal error is indicated as 11.7°. Figure 619 indicates that the 7" spheres should then be moved to the 11" position after slewing 15.5° clockwise so as to correct both the D and E errors. Using this chart eliminates trial-and-error adjustment methods for quadrantal errors and provides information for moving the spheres.

621. Corrector Magnet Inductions In Spheres

Should a ship have both spheres and many permanent B and C magnet correctors close to the compass, induction will exist between these correctors. This induction will require some shuttling back and forth between headings while making adjustments. This situation can be improved by using larger spheres further out, by approximately setting the spheres before starting adjustments, and by using more magnets further from the spheres and compass. Magnetized spheres Flinders bars will cause difficulty during adjustment, and introduce an unstable deviation curve if they suffer a change of magnetic condition.

622. Flinders Bar Effects

Figure 622 presents the approximate quadrantal error introduced by the presence of the Standard Navy Flinders bar. Since the Flinders bar is usually placed in the forward or aft position, it acts as a small minus D corrector as well as a corrector for vertical induced effects. This means that when inserting the Flinders bar, move the regular spheres closer to correct for the increased plus D error. Conversely, move the regular spheres away when removing the Flinders bar. This D error in the Flinders bar is due mostly to compass needle induction because the bar is small in cross-section and close to the compass. Such needle induction is practically constant; therefore, the deviation effects on the compass will change with magnetic latitudes because the directive force, H, changes. However, when balanced by sphere correctors, this effect tends to cancel out the variable part of the sphere correction caused by the compass needle induction.

623. Flinders Bar Adjustment

One must have reliable data obtained in two widely separated magnetic latitudes to place the correct amount of Flinders bar. Placing the Flinders bar by any other method is merely an approximation. Obtaining the required magnetic data will necessitate further refinements. There are several methods of acquiring and using latitude data in order to determine the proper amount of Flinders bar:

The data required for correct Flinders bar adjustment consists of accurate tables of deviations with details of corrector conditions at two different magnetic latitudes; the farther apart the better. Should it be impossible to swing ship for a complete table of deviations, the deviations on east and west magnetic headings would be helpful. Ship's log data is usually not reliable enough for Flinders bar calculation. Observe the following precautions when taking data. These precautions will ensure that deviation changes are due only to changes in the H and Z components of the earth's field.

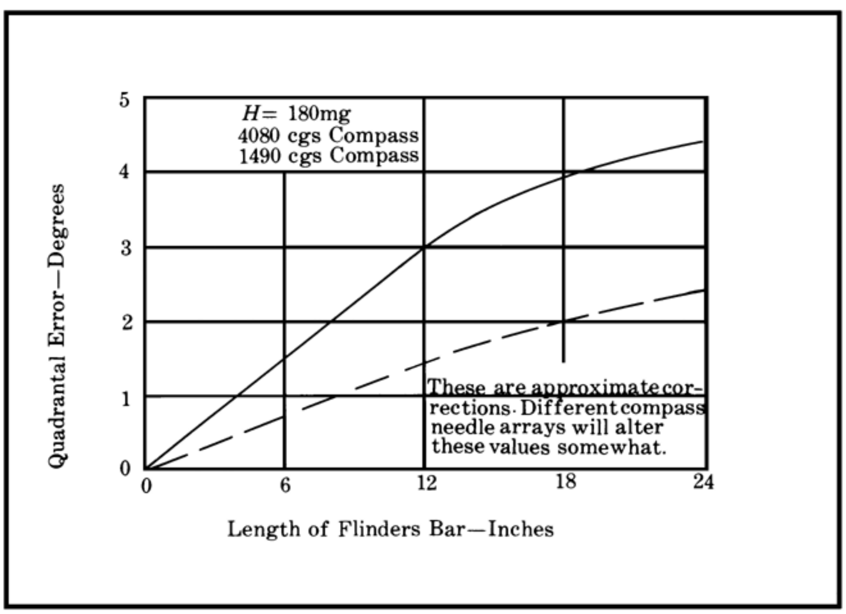


Figure 622. Quadrantal error from standard Navy Flinders bar.

1. Degaussing should be secured, by a reversal process if necessary, at both latitudes before data are taken.

2. If the ship has been in dock or steaming, on one heading for several days prior to the taking of these data, the resulting temporary magnetism (Gaussin error) would create erroneous deviations. A shakedown on other headings prior to taking data will reduce such errors.

3. Any major change in the ship's magnetic field (caused, for example, by deperming, structural changes, heavy gunfire, shifting magnetic cargoes) between data sets will make the comparative results meaningless.

4. Because the data will not be reliable if the ship's permanent magnetism changes between the two latitudes, it will likewise be unreliable if any of the binnacle correctors are changed.

In the event that an approximation as to Flinders bar length cannot be made, then the deviations at the two latitudes should be taken with no Flinders bar in the holder. This procedure would also simplify the resulting calculations.

624. Methods Of Determining Flinders Bar Length

Method 1. Having obtained reliable deviation data at two different magnetic latitudes, the changes in the deviations, if any, may justifiably be attributed to an incorrect Flinders bar adjustment. E/W and N/S deviations are the ones which are subject to major changes from such an incorrect adjustment. If there is no change in any of these deviations, the Flinders bar adjustment is probably correct. A change in the E/W deviations indicates an unsymmetrical arrangement of vertical iron forward or aft of the compass, which requires correction by the Flinders bar, forward or aft of the compass. A change in the N/S deviations indicates an unsymmetrical arrangement of vertical iron to port or starboard of the compass, which requires correction by the Flinders bar to port or starboard of the compass. This latter case is very rare, but can be corrected.

Determine the B deviations on magnetic east/west headings at both latitudes. The constant c may then be calculated from the following formula:

$$c = \lambda \frac{H_1 \tan B_1 - H_2 \tan B_2}{Z_1 - Z_2}$$

where

λ = shielding factor (0.7 to 1.0 average).
H_1 = earth's field, H, at 1st latitude.
B_1 = degrees B deviation at 1st latitude (magnetic headings).
Z_1 = earth's field, Z, at 1st latitude.
H_2 = earth's field, H, at 2nd latitude.
B_2 = degrees B deviation at 2nd latitude (magnetic headings).
Z_2 = earth's field, Z, at 2nd latitude.

This constant c represents a resultant mass of vertical iron in the ship which requires Flinders bar correction. If the Flinders bar is present at the time of calculations, it must be remembered that it is already correcting an amount of c

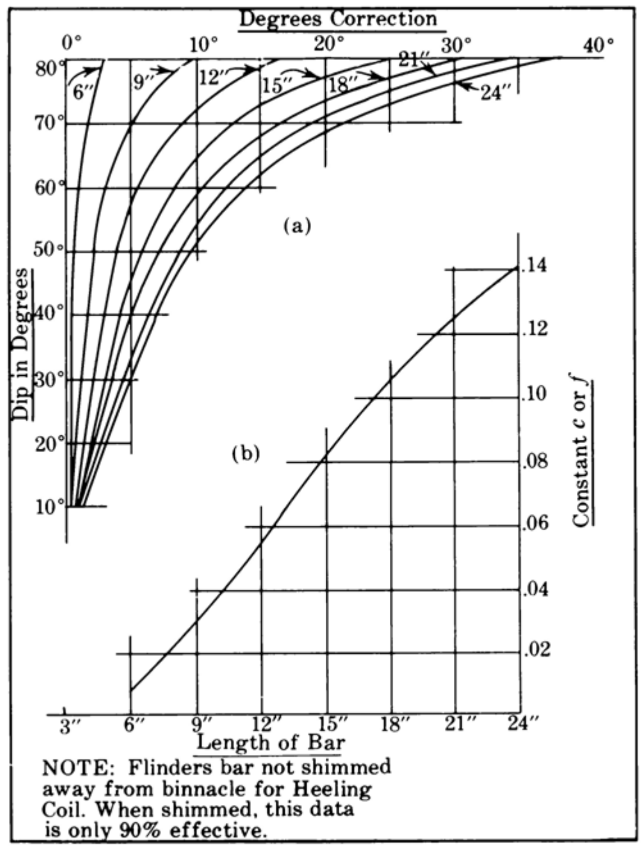


Figure 624a. Dip deviation curves for Flinders bar.

in the ship which must be added to the uncorrected c, calculated by the above formula. This total value of c is used in conjunction with Figure 624a to indicate, directly, the necessary total amount of Flinders bar. If this total c is negative, Flinders bar is required on the forward side of the binnacle; and if it is positive, a Flinders bar is required on the aft side of the binnacle. The iron sections of Flinders bar should be continuous and at the top of the tube with the longest section at the top. Wooden spacers are used at the bottom of the tube. It will be noted that the B deviations used in this formula are based on data on E/W magnetic headings rather than on compass headings, as with the approximate coefficients.

Method 2. Should the exact amount of correction required for vertical induction in the ship at some particular

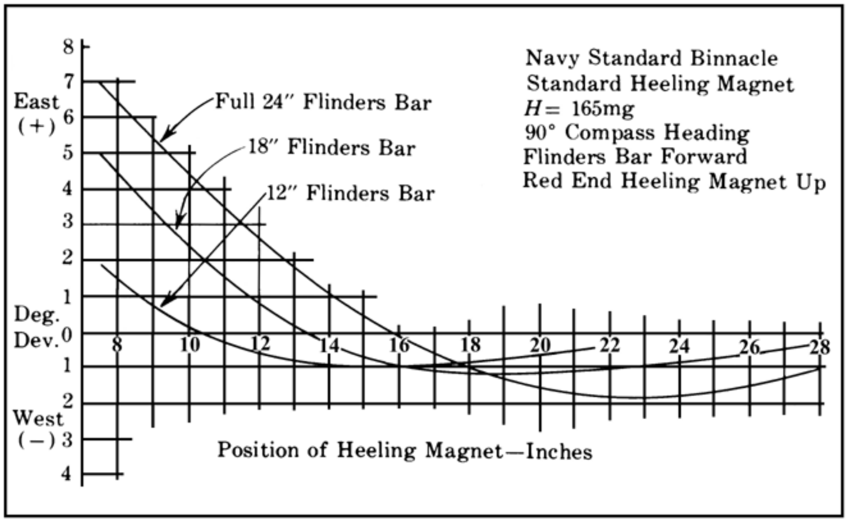


Figure 624b. Induction effects in Flinders bar due to heeling.

magnetic dip, q, be known, Figure 624a will directly indicate the correct amount of Flinders bar to be placed at the top of the holder. The exact amount of correction would be known when one of the latitudes is the magnetic equator, and the deviations there are negligible. Then the B deviation, in degrees, on magnetic headings at the other latitude, is the exact amount to correct by means of curves in Figure 624a.

Method 3. Lord Kelvin's rule for improving the Flinders bar setting is: "Correct the deviations observed on east or west courses by the use of fore-and-aft B magnets when the ship has arrived at places of weaker vertical magnetic field, and by the use of Flinders bar when she has arrived at places of stronger vertical magnetic field, whether in the Northern or Southern Hemisphere."

After determining the correct amount of Flinders bar, by either method (1) or (2) above, the bar should then be inserted at the top of the holder, and the fore-and-aft B magnets readjusted to correct the remaining B error. Sphere adjustments should likewise be refined.

It is quite possible that on inserting the Flinders bar, no visible deflection of the compass will be observed, even on an east or west heading. This should cause no concern because certain additional induction effects exist in the bar, from:

1. The heeling magnet.
2. The existing fore-and-aft magnets.
3. The vertical component of the ship's permanent magnetic field.

Figure 624b presents typical induction effects in the Flinders bar for different positions of heeling magnet. An adjuster familiar with the nature of these effects will appreciate the advantages of establishing the Flinders bar and heeling magnet combination before leaving dockside. Deviations must also be checked after adjusting the heeling magnet, if Flinders bar is present.

625. Slewing Of Flinders Bar

The need for slewing the Flinders bar is much more rare than that for slewing spheres. Also, the data necessary for slewing the Flinders bar cannot be obtained on a single latitude adjustment, as with the spheres. Slewing the bar to some intermediate position is, in effect, merely using one bar to do the work of two; one forward or aft, and the other port or starboard.

Section 624 explains that a change of the E/W deviations, with changes in latitude, indicates the need for Flinders bar forward or aft of the compass; and a change of the N/S deviations, with changes in latitude, indicates the need for Flinders bar to port or starboard of the compass.

A change of the B deviations on magnetic E/W headings is used, as explained in section 624, to determine the proper amount of Flinders bar forward or aft of the compass, by calculating the constant c.

If there is a change of the C deviations on magnetic N/S headings, a similar analysis may be made to determine the proper amount of Flinders bar to port or starboard of the compass by calculating the constant f from:

$$f = \lambda \frac{H_1 \tan C_1 - H_2 \tan C_2}{Z_1 - Z_2}$$

when

λ = shielding factor (0.7 to 1.0 average).

H_1 = earth's field, H, at 1st latitude.
C_1 = degrees C deviation at 1st latitude (magnetic headings).
Z_1 = earth's field, H, at 1st latitude.
H_2 = earth's field, H, at 2nd latitude.
C_2 = degrees C deviation at 2nd latitude (magnetic headings).
Z_2 = earth's field, Z, at 2nd latitude.

Any value of this *f* constant indicates the need for Flinders bar adjustment athwartship of the compass, just as a value of the c constant indicates the need for Flinders bar adjustment forward or aft of the compass. The *f* constant curve in Figure 624b is used for the determination of this Flinders bar length. If *f* is negative, Flinders bar is required on the starboard side of the binnacle.

Should both c and f exist on a ship, the angular position for a Flinders bar to correct the resultant vertical induction effects may be found by:

$$\tan\beta = \frac{f}{c} \quad \text{or} \quad \beta = \tan^{-1}\frac{f}{c}$$

β is the angle to slew the Flinders bar from the fore-and-aft axis. If *c* and *f* are negative, the bar will be slewed clockwise from the forward position; if *c* is negative and *f* is positive, the bar will be slewed counterclockwise from the aft position.

After determining the angle to slew the Flinders bar from the fore-and-aft line, the total amount of Flinders bar necessary to correct the resultant vertical induction effects in this position is found by:

$$r = \sqrt{c^2 + f^2}$$

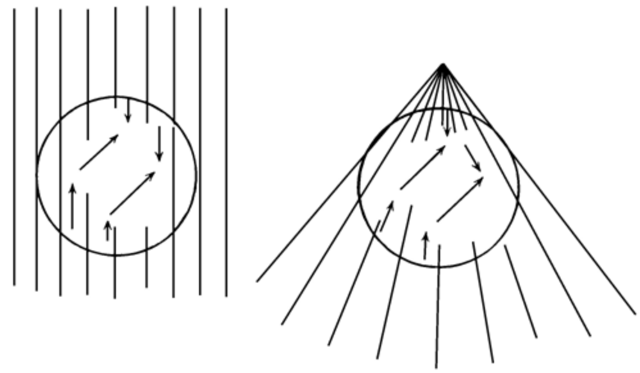
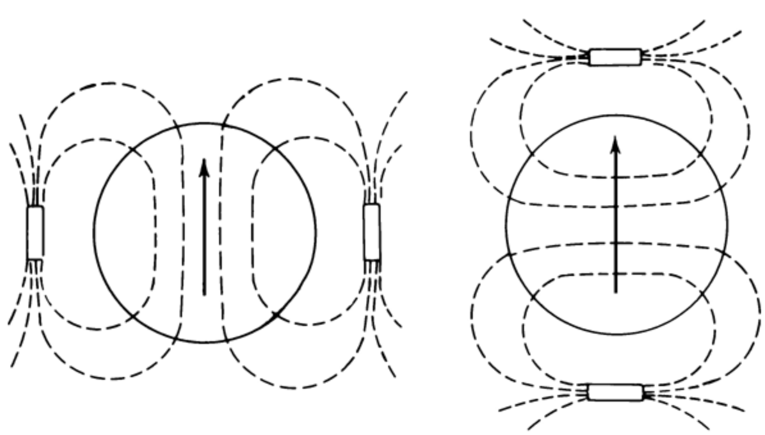


Figure 626a. Magnetic fields across compass needle arrays.

The constant *r* is then used on the *c* or *f* constant curve in Figure 624b to determine the total amount of Flinders bar necessary in the slewed position.

626. Compasses

Compasses themselves play a very important part in compass adjustment, although it is common belief that the compass is only an indicating instrument, aligning itself in the resultant magnetic field. This would be essentially true if the magnetic fields were uniform about the compass; but, unfortunately, magnetism close to the compass imposes nonuniform fields across the needles. In other words, adjustment and compensation sometimes employ non-uniform



B Magnet Fields

C Magnet Fields

Figure 626b. Arrangements of corrector magnets.

fields to correct uniform fields. Figure 626a indicates the difference between uniform and nonuniform field effects on a compass. Such unbalanced torques, arising from nonuniform magnetic fields, create deviations of the compass which have higher frequency characteristics. Compass designs include many combinations of different length needles, different numbers of needles, and different spacings and arrangements of needles all designed to minimize the higher order deviations resulting from such nonuniform magnetic fields. Although compass design is rather successful in minimizing such deviations, it is obvious that different compasses will be affected differently by the same magnetic fields. It is further stressed that, even with proper compass design, it is the responsibility of all adjusters to exercise care in applying correctors, in order to create the most uniform magnetic field possible.

This is the basis for the rule which requires the use of strong correctors symmetrically arranged, as far away from the compass as possible, instead of weak correctors very close to the compass. In general it is better to use larger spheres placed at the extremities of the brackets, equally distant from the center of the compass. B and C permanent magnet correctors should always be placed so as to have an equal number of magnets on both sides of the compass where possible. They should also be centered as indicated in Figure 626b, if regular tray arrangements are not available. The desire for symmetrical magnetic fields is one reason for maintaining a sphere of specified radius, commonly called the **magnetic circle**, about the magnetic compass location. This circle is kept free of any magnetic or electrical equipment.

The **magnetic moment** of the compass needle array, another factor in compass design, ranks in importance with the proper arrangement of needles. This magnetic moment controls the needle induction in the soft iron correctors, as discussed in section 619 and section 622, and hence governs the constancy of those corrector effects with changes in magnetic latitude. The $7^1/_2$" Navy No. 1 alcohol-water compass has a magnetic moment of approximately 4000 cgs units, whereas the $7^1/_2$" Navy No. 1 oil compass has a magnetic moment of approximately 1650 cgs units. The lower magnetic moment compass allows considerably less change in quadrantal correction, although the periods are essentially comparable, because of the difference in the compass fluid characteristics.

Other factors which must be considered in compass design are period, fluid, swirl, vibration, illumination, tilt, pivot friction, fluid expansion, and others. These factors, however, are less important from an adjuster's point of view than the magnetic moment and arrangement of needles, and are therefore not discussed further in this text.

SHIP'S HEADING

627. Ship's Heading

Ship's heading is the angle, expressed in degrees clockwise from north, of the ship's fore-and-aft line with respect to the true meridian or the magnetic meridian. When this angle is referred to the true meridian, it is called a **true heading**. When this angle is referred to the magnetic meridian, it is called a **magnetic heading**. Heading, as indicated on a particular compass, is termed the ship's compass heading by that compass. It is always *essential* to specify heading as true heading, magnetic heading, or compass heading. In order to obtain the heading of a ship, it is essential that the line through the pivot and the forward lubber's line of the compass be parallel to the fore-and-aft line of the ship. This applies also to the peloruses and gyro repeaters, which are used for observational purposes.

628. Variation And Deviation

Variation is the angle between the magnetic meridian and the true meridian at a given location. If the northerly part of the magnetic meridian lies to the right of the true meridian, the variation is easterly, and if this part is to the left of the true meridian, the variation is westerly. The local variation and its small **annual change** are noted on the compass rose of all navigational charts. Thus the true and magnetic headings of a ship differ by the local variation. Chart 42 shows approximate variation values for the world.

As previously explained, a ship's magnetic influence will generally cause the compass needle to deflect from the magnetic meridian. This angle of deflection is called **deviation**. If the north end of the needle points east of the magnetic meridian, the deviation is easterly; if it points west of the magnetic meridian, the deviation is westerly.

629. Heading Relationships

A summary of heading relationships follows:

1. **Deviation** is the difference between the compass heading and the magnetic heading.
2. **Variation** is the difference between the magnetic heading and the true heading.
3. The algebraic sum of deviation and variation is the **compass error**.

Figure 629 illustrates these relationships. The following simple rules will assist in naming errors and in converting from one heading to another:

1. Compass least, deviation east, compass best, deviation west.
2. When correcting, add easterly errors, subtract westerly errors.
3. When uncorrecting, subtract easterly errors, add westerly errors.

Typical heading relationships are as follows:

Compass	Deviation	Magnetic	Variation	True
358°	5°E	003°	6°E	009°
120°	1°W	119°	3°E	122°
180°	6°E	186°	8°W	178°
240°	5°W	235°	7°W	228°

Figure 629. Magnetic heading relationships.

Use the memory aid “Can Dead Men Vote Twice at Elections” to remember the conversion process (Compass, Deviation, Magnetic, Variation, True, add east). When converting Compass Heading to True Heading, add east deviations and variations and subtract west deviations and variations.

Complete facility with conversion of heading data is essential for expeditious compass adjustment.

630. Use Of Compass Heading And Magnetic Heading For Adjustment

The primary object of adjusting compasses is to reduce deviations; that is, to minimize the difference between the magnetic and compass headings. There are two methods for accomplishing this:

Method 1. Place the ship on the desired magnetic heading (section 631) and correct the compass so that it reads the same as this magnetic heading. This is the preferred method.

Method 2. Place the ship on the desired compass heading and determine the corresponding magnetic heading of the ship. Correct the compass so that it reads the same as this known magnetic heading. Use this method whenever it is impractical to place the ship on a steady magnetic heading for direct correction.

One can easily observe compass deviation when using the first method because it is simply the difference between the compass reading and the known magnetic heading of the ship. The difficulty in using this method lies in placing the ship on the desired magnetic heading and holding the ship steady on that heading while adjustments are being made.

The difficulty in using the second method lies in the determining deviation. Further difficulty arises because the

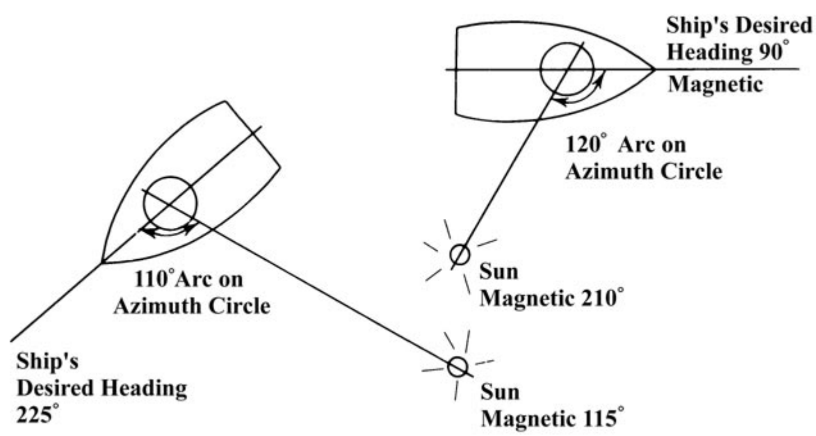


Figure 630. Azimuth circle set-ups.

helmsman steers by an uncorrected compass whose deviations are changing while the technician is making the necessary adjustments. Therefore, as each adjustment is being made, the helmsman should hold the ship's heading steady by some means other than the compass that is being corrected.

If the compass has no appreciable deviation, the deviation taken on compass headings will closely approximate those taken on magnetic headings. However, as the magnitude of errors increases, there will be a marked difference between the deviations taken on compass headings and those taken on magnetic headings.

631. Methods Of Placing Ship On Magnetic Headings

Method 1. Bring the ship onto a magnetic heading by referencing a gyrocompass. The magnetic variation applied to true heading determines the gyro course to be steered to place the ship on the required magnetic heading. Take gyrocompass error into consideration in determining gyro course to be steered.

The difference between gyro heading and magnetic heading will be constant on all headings as long as the gyrocompass error is constant and the variation does not change. Determine gyrocompass error by comparing the calculated true azimuth of the sun and the azimuth as observed on a synchronized repeater.

It should be remembered that gyrocompasses have certain errors resulting from latitude and speed changes, and these errors are not always constant on all headings. For these reasons, the gyro error must be checked constantly, especially if the gyro is being used to obtain data for determining residual deviation curves of the magnetic compass.

Method 2. Place the ship on a magnetic heading by aligning the vanes of an azimuth circle with the sun over the topside compass. The sun is a distant object whose azimuth (angle from the north) may be computed for any given time. Methods of calculating sun's azimuths are discussed in the next section. By setting the line of sight of the vanes at an angle to the right (or left) of the fore-and-aft line of the ship equal to the difference between the computed magnetic azimuth and the desired magnetic heading of the ship, and then swinging the ship until the sun is aligned with the vanes, the ship will be on the desired magnetic heading. Simple diagrams with the ship and sun drawn in their relative positions, will aid in visualizing each problem. Always keep the azimuth circle level while making observations. This holds especially true for observing celestial bodies.

Method 3. Use a distant object (10 or more miles away) with the azimuth circle when placing the ship on magnetic headings. This procedure is similar to that used with the sun except that the magnetic bearing of the object is constant. With an object 11.4 nautical miles distant, a change in position of 400 yards at right angles to the line of sight introduces an error of 1°.

Method 4. Use a pelorus to place a ship on a magnetic heading using the sun's azimuth in much the same manner as with the azimuth circle. Using the pelorus allows the magnetic heading of the ship to be observed continuously as the ship swings. Clamp the forward sight vane to the dial at the value of the sun's magnetic azimuth. Then, train the sight vanes so that the sun is reflected in the mirror. As the ship turns, observe the magnetic heading under the forward lubber's line. As the desired magnetic course is approached, the compass can be read and corrected even before that magnetic course is actually obtained. A final check can be made when the ship is on the exact course. Always keep the pelorus level while making observations, particularly of celestial bodies.

Method 5. A distant object can be used in conjunction with the pelorus, as with the azimuth circle, in order to place the ship on magnetic headings.

632. Methods Of Determining Deviations On Compass Heading

Method 1. Determine the compass' deviation by comparing the sun's calculated magnetic azimuth to the azimuth observed using an azimuth circle. The next section discusses methods of calculating the sun's azimuths. Place the ship on the desired compass heading and take an azimuth of the sun on the compass card's face. The difference between the observed azimuth and the calculated magnetic azimuth of the sun is the deviation on that compass course.

Method 2. Use the pelorus with the sun's azimuth to obtain deviations on compass headings. Bring the ship to the desired compass heading and set the forward sight vane on the value calculated for the sun's magnetic azimuth. Then train the sight vanes on the sun. The pelorus indicates the ship's magnetic heading. The difference in degrees between the compass heading and magnetic heading of the ship indicated by the pelorus is the deviation on that compass course.

Method 3. Use the azimuth circle or pelorus in conjunction with ranges or a distant object to obtain deviations on compass courses. The procedure is similar to that used with the sun. A range consists of any two objects or markers, one in the foreground and the other in the background, which establishes a line of sight having a known magnetic bearing. Determine the range's true bearing from a chart; then, convert this true bearing to the magnetic bearing by applying the variation listed on the chart. Bring the ship to the desired compass course and, at the instant of crossing the line of sight of the range, take a bearing to the range. With the azimuth circle, the difference between the observed range bearing and the known magnetic range bearing represents the deviation on that compass course. If using a pelorus, set the forward sight vanes to the magnetic bearing of the range and read the ship's magnetic heading when taking a sight on the range. The deviation is the difference between the compass heading of the ship and the known

magnetic heading of the ship as indicated by pelorus.

Method 4. Obtain deviations on compass courses by using reciprocal bearings. Set up a pelorus on shore and align the dial's south end with magnetic north. A ship then sights the pelorus on shore, using an azimuth circle or pelorus, at the same instant the observer on shore sights the ship. The ship's bearing from shore on the reversed pelorus is the magnetic bearing of the shore position from the ship. Continuous communication between ship and shore is necessary when employing this method.

Additional methods of determining deviations are by the use of azimuths of the moon, stars, and planets.

AZIMUTHS

633. Azimuths Of The Sun

The sun is a valuable reference point for compass adjustment because one can easily obtain accurate compass bearings of the sun and compare these bearings with the sun's calculated true bearing (azimuth) to obtain compass error. One can use the azimuths of other celestial bodies to make this comparison; however, none are as convenient as the sun.

Calculating an azimuth of the sun is covered in Chapter 17.

634. Curve Of Magnetic Azimuths

During the course of compass adjustment and swinging ship, a magnetic direction is needed many times, either to place the vessel on desired magnetic headings or to determine the deviation of the compass being adjusted. The sun's azimuth continually changes as the earth rotates. Compensate for this by preparing a **curve of magnetic azimuths**. Compute true azimuths at frequent intervals. Then, apply the variation at the center of the maneuvering area to determine the equivalent magnetic azimuths. Plot the magnetic azimuths versus time and fair a curve through the points. Plotting at least three points at intervals of half an hour is usually sufficient. If the sun is near the celestial meridian and relatively high in the sky, plot additional points.

Unless extreme accuracy is required, determine the Greenwich hour angle and declination for the approximate midtime. Additionally, use the same declination for all computations. Assume the Greenwich hour angle increase at 15° per hour.

TRANSIENT DEVIATIONS OF THE MAGNETIC COMPASS

635. Stability

So far this chapter has discussed only the principles of steady-state magnetism. However, a carefully made correction based on these steady-state phenomenon may turn out to be inaccurate due to transient magnetic effects. A compass adjuster cannot place correctors on the binnacle for such variable effects; he must recognize and handle them in the best possible manner. A good adjuster not only provides an accurate deviation curve which is reliable under steady state conditions, but he also records transient magnetic effects which cannot be eliminated.

636. Sources Of Transient Error

The magnetic circle about the magnetic compass is intended to reduce any transient conditions, but there still are many items which cause the compass to act erratically. The following is a list of some such items. If in doubt about the effect of an item on compass performance, a test can be made by swinging any movable object or energizing any electrical unit while observing the compass for deviations. This would best be tried on two different headings 90° apart, since the compass might possibly be affected on one heading and not on another.

Some magnetic items which cause variable deviations if placed too close to the compass are as follows:

1. Guns on movable mounts.
2. Ready ammunition boxes.
3. Variable quantities of ammunition in ready boxes.
4. Magnetic cargo.
5. Hoisting booms.
6. Cable reels.
7. Metal doors in wheelhouse.
8. Chart table drawers.
9. Movable gyro repeater.
10. Windows and ports.
11. Signal pistols racked near compass.
12. Sound powered telephones.
13. Magnetic wheel or rudder mechanism.
14. Knives or tools near binnacle.
15. Watches, wrist bands, spectacle frames.
16. Hat grommets, belt buckles, metal pencils.
17. Heating of smoke stack, or exhaust pipes.
18. Landing boats.

Some electrical items which cause variable deviations if placed too close to the compass are:

1. Electric motors.
2. Magnetic controllers.
3. Gyro repeaters.
4. Nonmarried conductors.
5. Loudspeakers.
6. Electric indicators.
7. Electric welding.
8. Large power circuits.
9. Searchlights.
10. Electrical control panels or switches.
11. Telephone headsets.
12. Windshield wipers.
13. Rudder position indicators, solenoid type.
14. Minesweeping power circuits.
15. Engine order telegraphs.
16. Radar equipment.
17. Magnetically controlled switches.
18. Radio transmitters.
19. Radio receivers.
20. Voltage regulators.

Another source of transient deviation is the **retentive error**. This error results from the tendency of a ship's structure to retain some of the induced magnetic effects for short periods of time. For example, a ship traveling north for several days, especially if pounding in heavy seas, will tend to retain some fore-and-aft magnetism hammered in under these induction conditions. Although this effect is transient, it may cause incorrect observations or adjustments. This same type of error occurs when ships are docked on one heading for long periods of time. A short shakedown, with the ship on other headings, will tend to remove such errors. A similar sort of residual magnetism is left in many ships if the degaussing circuits are not secured by the reversal sequence.

A source of transient deviation trouble shorter in duration than retentive error is known as **Gaussin error**. This error is caused by eddy currents set up by a changing number of magnetic lines of force through soft iron as the ship changes heading. Due to these eddy currents, the induced magnetism on a given heading does not arrive at its normal value until about 2 minutes after changing to the heading.

Deperming and other magnetic treatment will change the magnetic condition of the vessel and therefore require compass readjustment. The decaying effects of deperming are sometimes very rapid. Therefore, it is best to delay readjustment for several days after such treatment. Since the magnetic fields used for such treatments are sometimes rather large at the compass locations, the Flinders bar, compass, and related equipment are sometimes removed from the ship during these operations.

HEELING ADJUSTMENTS

637. Use Of The Dip Needle In Heeling Adjustments

The heeling effects of both the permanent and induced magnetism are corrected by adjusting the position of the vertical permanent heeling magnet. This adjustment can be made in either of two ways:

Method 1. With the ship on an even keel and as close to the east or west magnetic heading as possible, adjust the heeling magnet until a dip needle inserted in the compass position is balanced at some predetermined position.

Method 2. Adjust the heeling magnet, while the ship is rolling on north and south headings, until the oscillations of the compass card have been reduced to an average minimum.

To establish an induction condition between the heeling magnet and Flinders bar and to minimize heeling oscillations before at-sea adjustments, set the heeling magnet at dockside by the first method above. Further, position the Flinders bar and spheres before making any heeling adjustments because of the heeling correction and shielding effect they produce.

Readjust the heeling magnet when the ship changes magnetic latitude appreciably because the heeling magnet corrects for induced as well as permanent magnetic effects. Moving the heeling magnet with Flinders bar in the holder will change the induction effects in the Flinders bar and consequently change the compass deviations. Thus, the navigator is responsible for:

1. Moving the heeling magnet up or down (invert when necessary) as the ship changes magnetic latitude, to maintain a good heeling adjustment for all latitudes.

2. Checking his deviations and noting changes resulting from movements of the heeling magnet when Flinders bar is in the holder. Any deviation changes should be either recorded or readjusted by means of the fore-and-aft B magnets.

There are two types of dip needles. One assumes the angle of inclination for its particular location, and one uses a moveable weight to balance any magnetic torque. The latter type renders the needle's final position more independent of the horizontal component of magnetic fields. It, therefore, is more useful on uncorrected compasses.

For ships with no shielding of the earth's field at the compass (having no surrounding metal structure), the procedure for adjusting the heeling magnet is quite simple. Take the dip needle to a nearby area where there is no local magnetic attraction, level the instrument, and set the weight to balance the needle. It is preferable to align the instrument so that the north seeking end of the needle is pointing north. Next, level the instrument in the compass position on board ship, place the spheres in their approximate position, and adjust the heeling magnet until the needle assumes the balanced condition. This presumes that all the effects of the ship are canceled, leaving only the effect of the vertical earth's field. Secure the degaussing circuits during this adjustment.

Some ships have shielding effects at the compass. Such would be the case for a metal enclosed wheelhouses. In this case, the procedure is essentially the same as above except that the weight on the dip needle should be moved toward the pivot to balance against some lesser value of earth's field. The new position of the weight, expressed in centimeters from the pivot, can be approximately determined by multiplying the value of lambda, λ, for the compass location by the original distance of the weight from the pivot in centimeters. Should λ, for the compass location be unknown, it may generally be considered as about 0.8 for steering compass locations and 0.9 for standard compass locations. By either method, the weight on the dip needle should be moved into its new position. Next, level the instrument in the compass position on board ship and adjust the heeling magnet until the needle assumes the balanced condition.

Theoretically, these methods of adjusting the heeling magnet with a dip needle should be employed only with the ship on east or west magnetic headings. This avoids heeling errors resulting from unsymmetrical induced magnetism. If it is impractical to place the ship on such a heading, make approximations on any heading and refine these approximations when convenient.

To summarize, a successful heeling magnet adjustment is one which minimizes the compass oscillations caused by the ship's rolling. Therefore, the rolling method is a visual method of adjusting the heeling magnet or checking the accuracy of the last heeling magnet adjustment. Generally, the oscillation effects due to roll on both the north and south compass headings will be the same. However, some unsymmetrical arrangements of fore-and-aft soft iron will introduce different oscillation effects on these two headings. Such effects cannot be entirely eliminated on both headings with one setting of the heeling magnet. Therefore, the heeling magnet is generally set for the average minimum oscillation condition.

USE OF THE HORIZONTAL FORCE INSTRUMENT

638. Determining The Horizontal Shielding Factor

Occasionally, the navigator must determine the magnetic field strength at some compass location for one of the following reasons:

1. To determine the horizontal shielding factor, lambda (λ), for:
    a. A complete mathematical analysis.
    b. Accurate Flinders bar adjustment.
    c. Accurate heeling adjustment.
    d. Calculations on a dockside magnetic adjustment.
    e. Determining the best compass location on board ship.
2. To make a dockside magnetic adjustment for determining the magnitude and direction of the existing directive force at the magnetic compass.

The **horizontal shielding factor** is the ratio of the reduced earth's directive force, H', on the compass to the horizontal earth's field, H.

$$\lambda = \frac{H'}{H}$$

The navigator can determine λ for a compass location by making a measurement of the reduced earth's directive force, H'. On a corrected compass, this value H' may be measured with the ship on any heading, since this reduced earth's directive force is the only force acting on the compass. If the compass is not corrected for the ship's magnetism and the deviations are large, H' is determined from the several resultant directive forces observed with equally spaced headings of the ship. The Horizontal Shielding Factor should be determined for every compass location on every ship.

639. Measurement Of Magnetic Fields

Use a suitable **magnetometer** or a **horizontal force instrument** to measure magnetic fields. The magnetometer method is a direct reading method requiring no calculation. However, the force instrument method requires much less complicated test equipment so this method is discussed below.

The horizontal force instrument is simply a magnetized needle pivoted in a horizontal plane, much the same as a compass. It will settle in some position which will indicate the direction of the resultant magnetic field. Determine the resulting field's strength by comparing it with a known field. If the force needle is started swinging, it will be damped down with a certain period of oscillation dependent upon the strength of the surrounding magnetic field. The stronger the magnetic field, the shorter the period of time for each cycle of swing. The ratio is such that the squares of the period of vibration are inversely proportional to the strengths of the magnetic fields. This relationship is expressed as follows:

$$\frac{H'}{H} = \frac{T^2}{T'^2}$$

In the above formula, let H represent the strength of the earth's horizontal field in gauss and T represent the time in seconds for 10 cycles of needle vibration in that earth's field. A comparative measurement of time in seconds, T', for 10 cycles of vibration of the same needle in the unknown field will enable the navigator to calculate H'.

Since λ is the ratio of two magnetic field strengths, it may be found directly by the inverse ratio of the squares of the periods of vibration for the same horizontal force instrument in the two different magnetic fields by the same formula, without bothering about the values of H and H'.

The above may be used on one heading of the ship if the compass deviations are less than 4°.

$$\lambda = \frac{H'}{H} = \frac{T^2}{T'^2}$$

Use the following equation to obtain a more precise value of λ, and where compass deviations exceed 4°:

$$\lambda = \frac{T^2}{4}\left[\frac{\cos d_n}{T^2{}_n} + \frac{\cos d_e}{T^2{}_e} + \frac{\cos d_s}{T^2{}_s} + \frac{\cos d_w}{T^2{}_w}\right]$$

where:

T is the time period for the field H.

T_n is the time period for the resultant field on a north heading, etc.

$\cos d_n$ is the cos of the deviation on the north heading, etc.

DEGAUSSING (MAGNETIC SILENCING) COMPENSATION

640. Degaussing

A steel vessel has a certain amount of **permanent magnetism** in its "hard" iron and **induced magnetism** in its "soft" iron. Whenever two or more magnetic fields occupy the same space, the total field is the vector sum of the individual fields. Thus, near the magnetic field of a vessel, the total field is the combined total of the earth's field and the vessel's field. Therefore, the earth's magnetic field is altered slightly by the vessel.

Since certain mines are triggered by a vessel's magnetic influence of a vessel passing near them, a vessel tries to minimize its magnetic field. One method of doing this is to neutralize each component of the field with an opposite electromagnetic field produced by electric cables coiled around the vessel. These cables, when energized, counteract the permanent magnetism of the vessel, rendering it magnetically neutral. This obviously has severe effects on magnetic compasses.

A unit sometimes used for measuring the strength of a magnetic field is the **gauss**. Reducing of the strength of a magnetic field decreases the number of gauss in that field. Hence, the process is called **degaussing**.

When a vessel's degaussing coils are energized, the magnetic field of the vessel is completely altered. This introduces large deviations in the magnetic compasses. This is removed by introducing at the magnetic compass an equal and opposite force with energized coils. This is called **compass compensation**. When there is a possibility of confusion with compass adjustment to neutralize the effects of the natural magnetism of the vessel, the expression **degaussing compensation** is used. Since compensation may not be perfect, a small amount of deviation due to degaussing may remain on certain headings. This is the reason for swinging the ship with degaussing off and with it on. This procedure leads to having two separate columns in the deviation table.

641. A Vessel's Magnetic Signature

A simplified diagram of the distortion of the earth's magnetic field in the vicinity of a steel vessel is shown in Figure 641a. The field strength is directly proportional to the line spacing density. If a vessel passes over a device for detecting and recording the strength of the magnetic field, a certain pattern is traced. Figure 641b shows this pattern. Since the magnetic field of each vessel is different, each produces a distinctive trace. This distinctive trace is referred to as the vessel's **magnetic signature**.

Several **degaussing stations** have been established to determine magnetic signatures and recommend the currents needed in the various degaussing coils. Since a vessel's induced magnetism varies with heading and magnetic latitude, the current settings of the coils may sometimes need to be changed. A **degaussing folder** is provided each vessel to indicate the changes and to give other pertinent information.

A vessel's permanent magnetism changes somewhat with time and the magnetic history of the vessel. Therefore, the data in the degaussing folder should be checked periodically at the magnetic station.

642. Degaussing Coils

For degaussing purposes, the total field of the vessel is divided into three components: (1) vertical, (2) horizontal fore-and-aft, and (3) horizontal athwartships. The positive (+) directions are considered downward, forward, and to port, respectively. These are the normal directions for a vessel headed north or east in north latitude. Each

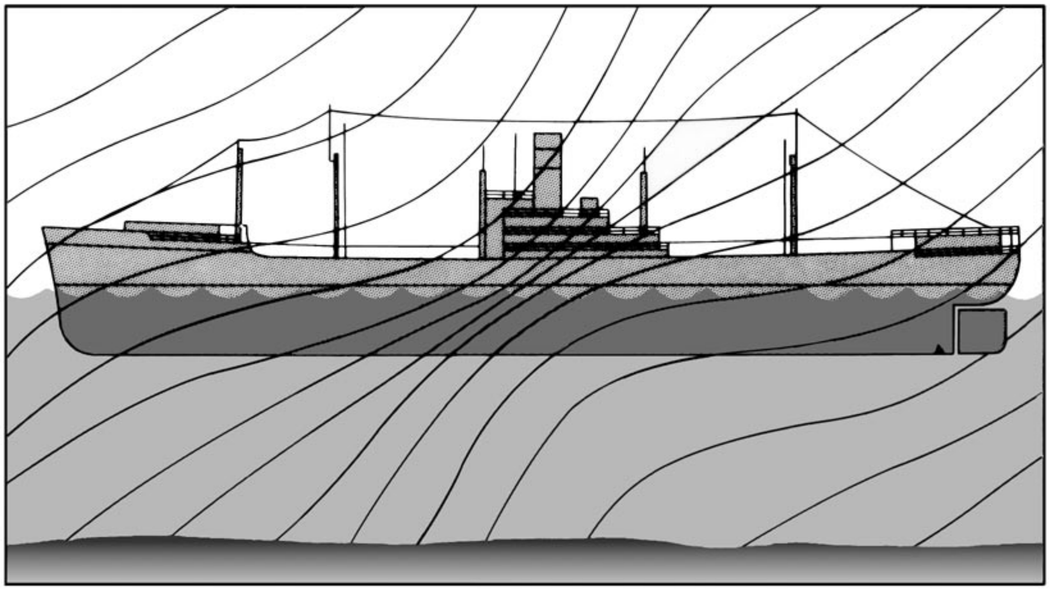


Figure 641a. Simplified diagram of distortion of earth’s magnetic field in the vicinity of a steel vessel.

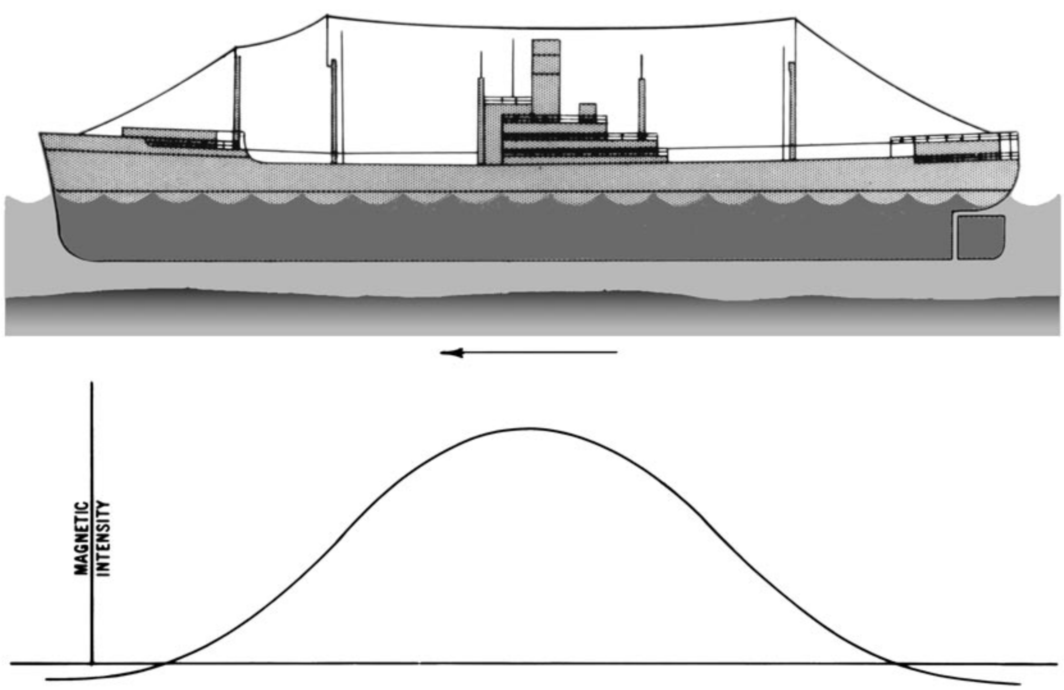


Figure 641b. A simplified signature of a vessel of Figure 641a.

component is opposed by a separate degaussing field just strong enough to neutralize it. Ideally, when this has been done, the earth's field passes through the vessel smoothly and without distortion. The opposing degaussing fields are produced by direct current flowing in coils of wire. Each of the degaussing coils is placed so that the field it produces is directed to oppose one component of the ship's field.

The number of coils installed depends upon the magnetic characteristics of the vessel, and the degree of safety desired. The ship's permanent and induced magnetism may be neutralized separately so that control of induced magnetism can be varied as heading and latitude change, without disturbing the fields opposing the vessel's permanent field. The principal coils employed are the following:

Main (M) coil. The M coil is horizontal and completely encircles the vessel, usually at or near the waterline. Its function is to oppose the vertical component of the vessel's permanent and induced fields combined. Generally the induced field predominates. Current in the M-coil is varied or reversed according to the change of the induced component of the vertical field with latitude.

Forecastle (F) and **quarterdeck (Q) coils**. The F and Q coils are placed horizontal just below the forward and after thirds (or quarters), respectively, of the weather deck. The designation "Q" for quarterdeck is reminiscent of the days before World War II when the "quarterdeck" of naval vessels was aft along the ship's quarter. These coils, in which current can be individually adjusted, remove much of the fore-and-aft component of the ship's permanent and induced fields. More commonly, the combined F and Q coils consist of two parts; one part the FP and QP coils, to take care of the permanent fore-and-aft field, and the other part, the FI and QI coils, to neutralize the induced fore-and-aft field. Generally, the forward and after coils of each type are connected in series, forming a split-coil installation and designated FP-QP coils and FI-QI coils. Current in the FP-QP coils is generally constant, but in the FI-QI coils is varied according to the heading and magnetic latitude of the vessel. In split-coil installations, the coil designations are often called simply the P-coil and I-coil.

Longitudinal (L) coil. Better control of the fore-and-aft components, but at greater installation expense, is provided by placing a series of vertical, athwartship coils along the length of the ship. It is the field, not the coils, which is longitudinal. Current in an L coil is varied as with the FI-QI coils. It is maximum on north and south headings, and zero on east and west headings.

Athwartship (A) coil. The A coil is in a vertical fore-and-aft plane, thus producing a horizontal athwartship field which neutralizes the athwartship component of the vessel's field. In most vessels, this component of the permanent field is small and can be ignored. Since the A-coil neutralizes the induced field, primarily, the current is changed with magnetic latitude and with heading, maximum on east or west headings, and zero on north or south headings.

The strength and direction of the current in each coil is indicated and adjusted at a control panel accessible to the navigator. Current may be controlled directly by rheostats at the control panel or remotely by push buttons which operate rheostats in the engine room.

Appropriate values of the current in each coil are determined at a degaussing station, where the various currents are adjusted until the vessel's magnetic signature is made as flat as possible. Recommended current values and directions for all headings and magnetic latitudes are set forth in the vessel's degaussing folder. This document is normally kept by the navigator, whose must see that the recommended settings are maintained whenever the degaussing system is energized.

643. Securing The Degaussing System

Unless the degaussing system is properly secured, residual magnetism may remain in the vessel. During degaussing compensation and at other times, as recommended in the degaussing folder, the "reversal" method is used. The steps in the reversal process are as follows:

1. Start with maximum degaussing current used since the system was last energized.
2. Decrease current to zero and increase it in the opposite direction to the same value as in step 1.
3. Decrease the current to zero and increase it to three-fourths maximum value in the original direction.
4. Decrease the current to zero and increase it to one-half maximum value in the opposite direction.
5. Decrease the current to zero and increase it to one-fourth maximum value in the original direction.
6. Decrease the current to zero and increase it to one-eighth maximum value in the opposite direction.
7. Decrease the current to zero and open switch.

644. Magnetic Treatment Of Vessels

In some instances, degaussing can be made more effective by changing the magnetic characteristics of the vessel by a process known as **deperming**. Heavy cables are wound around the vessel in an athwartship direction, forming vertical loops around the longitudinal axis of the vessel. The loops are run beneath the keel, up the sides, and over the top of the weather deck at closely spaced equal intervals along the entire length of the vessel. Predetermined values of direct current are then passed through the coils. When the desired magnetic characteristics have been acquired, the cables are removed.

A vessel which does not have degaussing coils, or which has a degaussing system which is inoperative, can be given some temporary protection by a process known as **flashing**. A horizontal coil is placed around the outside of the vessel and energized with large predetermined values of direct current. When the vessel has acquired a vertical field of permanent magnetism of the correct magnitude and polarity to reduce to a minimum the resultant field below the vessel for the particular magnetic latitude involved, the cable is removed. This type protection is not as satisfactory as

that provided by degaussing coils because it is not adjustable for various headings and magnetic latitudes, and also because the vessel's magnetism slowly readjusts following treatment.

During magnetic treatment all magnetic compasses and Flinders bars should be removed from the ship. Permanent adjusting magnets and quadrantal correctors are not materially affected, and need not be removed. If it is impractical to remove a compass, the cables used for magnetic treatment should be kept as far as practical from it.

645. Degaussing Effects

The degaussing of ships for protection against magnetic mines creates additional effects upon magnetic compasses, which are somewhat different from the permanent and induced magnetic effects. The degaussing effects are electromagnetic, and depend on:

1. Number and type of degaussing coils installed.
2. Magnetic strength and polarity of the degaussing coils.
3. Relative location of the different degaussing coils with respect to the binnacle.
4. Presence of masses of steel, which would tend to concentrate or distort magnetic fields in the vicinity of the binnacle.
5. The fact that degaussing coils are operated intermittently, with variable current values, and with different polarities, as dictated by necessary degaussing conditions.

646. Degaussing Compensation

The magnetic fields created by the degaussing coils would render the vessel's magnetic compasses useless unless compensated. This is accomplished by subjecting the compass to compensating fields along three mutually perpendicular axes. These fields are provided by small **compensating coils** adjacent to the compass. In nearly all installations, one of these coils, the **heeling coil**, is horizontal and on the same plane as the compass card, providing a vertical compensating field. Current in the heeling coil is adjusted until the vertical component of the total degaussing field is neutralized. The other compensating coils provide horizontal fields perpendicular to each other. Current is varied in these coils until their resultant field is equal and opposite to the horizontal component of the degaussing field. In early installations, these horizontal fields were directed fore-and-aft and athwartships by placing the coils around the Flinders bar and the quadrantal spheres. Compactness and other advantages are gained by placing the coils on perpendicular axes extending 045°-225° and 315°-135° relative to the heading. A frequently used compensating installation, called the **type K**, is shown in Figure 646. It consists of a heeling coil extending completely around the top of the binnacle, four **intercardinal coils**, and three control boxes. The intercardinal coils are named for their positions relative to the compass when the vessel is on a heading of north, and also for the compass headings on which the current in the coils is adjusted to the correct amount for compensation. The NE-SW coils operate together as one set, and the NW-SE coils operate as another. One control box is provided for each set, and one for the heeling coil.

The compass compensating coils are connected to the power supply of the degaussing coils, and the currents passing through the compensating coils are adjusted by series resistances so that the compensating field is equal to the degaussing field. Thus, a change in the degaussing currents is accompanied by a proportional change in the compensating currents. Each coil has a separate winding for each degaussing circuit it compensates.

Degaussing compensation is carried out while the vessel is moored at the shipyard where the degaussing coils are installed. This is usually done by civilian professionals, using the following procedure:

Step 1. The compass is removed from its binnacle and a dip needle is installed in its place. The M coil and heeling coil are then energized, and the current in the heeling coil is adjusted until the dip needle indicates the correct value for

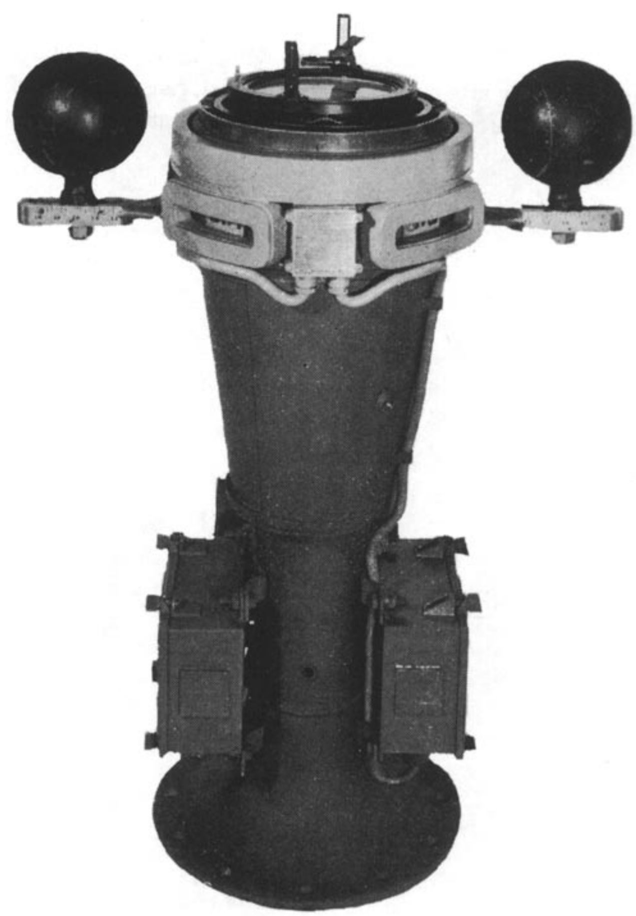


Figure 646. Type K degaussing compensation installation.

the magnetic latitude of the vessel. The system is then secured by the reversing process.

Step 2. The compass is replaced in the binnacle. With auxiliary magnets, the compass card is deflected until the compass magnets are parallel to one of the compensating coils or set of coils used to produce a horizontal field. The compass magnets are then *perpendicular* to the field produced by that coil. One of the degaussing circuits producing a horizontal field, and its compensating winding, are then energized, and the current in the compensating winding is adjusted until the compass reading returns to the value it had before the degaussing circuit was energized. The system is then secured by the reversing process. The process is repeated with each additional circuit used to create a horizontal field. The auxiliary magnets are then removed.

Step 3. The auxiliary magnets are placed so that the compass magnets are parallel to the other compensating coils or set of coils used to produce a horizontal field. The procedure of step 2 is then repeated for each circuit producing a horizontal field.

When the vessel gets under way, it proceeds to a suitable maneuvering area. The vessel is then headed so that the compass magnets are parallel first to one compensating coil or set of coils and then the other, and any needed adjustment is made in the compensating circuits to reduce the error to a minimum. The vessel is then swung for residual deviation, first with degaussing off and then with degaussing on, and the correct current settings for each heading at the magnetic latitude of the vessel. From the values thus obtained, the “DG OFF” and “DG ON” columns of the deviation table are filled in. If the results indicate satisfactory compensation, a record is made of the degaussing coil settings and the resistance, voltages, and currents in the compensating coil circuits. The control boxes are then secured.

Under normal operating conditions, the settings need not be changed unless changes are made in the degaussing system, or unless an alteration is made in the amount of Flinders bar or the setting of the quadrantal correctors. However, it is possible for a ground to occur in the coils or control box if the circuits are not adequately protected from moisture. If this occurs, it should be reflected by a change in deviation with degaussing on, or by a decreased installation resistance. Under these conditions, compensation should be done again. If the compass will be used with degaussing on before the ship can be returned to a shipyard where the compensation can be made by experienced personnel, the compensation should be made at sea on the actual headings needed, rather than by deflection of the compass needles by magnets. More complete information related to this process is given in the degaussing folder.

If a vessel has been given magnetic treatment, its magnetic properties have been changed. This necessitates readjustment of *each* magnetic compass. This is best delayed for several days to permit stabilization of the magnetic characteristics of the vessel. If compensation cannot be delayed, the vessel should be swung again for residual deviation after a few days. Degaussing compensation should not be made until after compass adjustment has been completed.

CHAPTER 7

DEAD RECKONING

DEFINITION AND PURPOSE

700. The Importance Of Dead Reckoning

Dead reckoning allows a navigator to determine his present position by projecting his past courses steered and speeds over ground from a known past position. He can also determine his future position by projecting an ordered course and speed of advance from a known present position. The DR position is only an approximate position because it does not allow for the effect of leeway, current, helmsman error, or gyro error.

Dead reckoning helps in determining sunrise and sunset; in predicting landfall, sighting lights and predicting arrival times; and in evaluating the accuracy of electronic positioning information. It also helps in predicting which celestial bodies will be available for future observation.

The navigator should carefully tend his DR plot, update it when required, use it to evaluate external forces acting on his ship, and consult it to avoid potential navigation hazards.

CONSTRUCTING THE DEAD RECKONING PLOT

Maintain the DR plot directly on the chart in use. DR at least two fix intervals ahead while piloting. If transiting in the open ocean, maintain the DR at least four hours ahead of the last fix position. If operating in a defined, small operating area, there is no need to extend the DR out of the operating area; extend it only to the operating area boundary. Maintaining the DR plot directly on the chart allows the navigator to evaluate a vessel's future position in relation to charted navigation hazards. It also allows the conning officer and captain to plan course and speed changes required to meet any operational commitments.

This section will discuss how to construct the DR plot.

701. Measuring Courses And Distances

To measure courses, use the chart's compass rose nearest to the chart section currently in use. Transfer course lines to and from the compass rose using parallel rulers, rolling rulers, or triangles. If using a parallel motion plotter (PMP), simply set the plotter at the desired course and plot that course directly on the chart.

The navigator can measure direction at any convenient place on a Mercator chart because the meridians are parallel to each other and a line making an angle with any one makes the same angle with all others. Measure direction on a conformal chart having nonparallel meridians at the meridian closest to the area of the chart in use. The only common nonconformal projection used is the gnomonic; a gnomonic chart usually contains instructions for measuring direction.

Compass roses give both true and magnetic directions. For most purposes, use true directions.

Measure distances using the chart's latitude scale. Assuming that one minute of latitude equals one nautical mile introduces no significant error. Since the Mercator's latitude scale expands as latitude increases, measure distances on the latitude scale closest to the area of interest. On large scale charts, such as harbor charts, use the distance scale provided. To measure long distances on small-scale charts, break the distance into a number of segments and measure each segment at its mid-latitude.

Navigational computers can also compute distances between two points. Because of the errors inherent in manually measuring track distances, use a navigation computer if one is available.

702. Plotting And Labeling The Course Line And Positions

Draw a new **course line** whenever restarting the DR. Extend the course line from a fix in the direction of the ordered course. Above the course line place a capital C followed by the ordered course. Below the course line, place a capital S followed by the speed in knots. Label all course lines and fixes soon after plotting them because a conning officer or navigator can easily misinterpret an unlabeled line or position.

Enclose a fix from two or more LOPs by a small circle and label it with the time to the nearest minute. Mark a DR position with a semicircle and the time. Mark an **estimated position (EP)** by a small square and the time. Determining an EP is covered later in this chapter.

Express the time using four digits without punctuation. Use either zone time or GMT.

Label the plot neatly, succinctly, and clearly.

Figure 702 illustrates this process. The navigator plots and labels the 0800 fix. The conning officer orders a course

of 095°T and a speed of 15 knots. The navigator extends the course line from the 0800 fix in a direction of 095°T. He calculates that in one hour at 15 knots he will travel 15 nautical miles. He measures 15 nautical miles from the 0800 fix position along the course line and marks that point on the course line with a semicircle. He labels this DR with the time. Note that, by convention, he labels the fix time horizontally and the DR time diagonally.

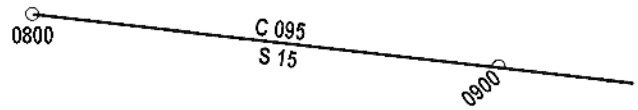


Figure 702. A course line with labels.

THE RULES OF DEAD RECKONING

703. Plotting The DR

Plot the vessel's DR position:

1. At least every hour on the hour.
2. After every change of course or speed.
3. After every fix or running fix.
4. After plotting a single line of position.

Figure 703 illustrates applying these rules. Clearing the harbor at 0900, the navigator obtains a last visual fix. This is **taking departure**, and the position determined is called the **departure**. At the 0900 departure, the conning officer orders a course of 090°T and a speed of 10 knots. The navigator lays out the 090°T course line from the departure.

At 1000, the navigator plots a DR position according to the rule requiring plotting a DR position at least every hour on the hour. At 1030, the conning officer orders a course change to 060°T. The navigator plots the 1030 DR position in accordance with the rule requiring plotting a DR position at every course and speed change. Note that the course line changes at 1030 to 060°T to conform to the new course. At 1100, the conning officer changes course back to 090°T. The navigator plots an 1100 DR because of the course change, Note that, regardless of the course change, an 1100 DR would have been required because of the "every hour on the hour" rule.

At 1200, the conning officer changes course to 180°T and speed to 5 knots. The navigator plots the 1200 DR. At 1300, the navigator obtains a fix. Note that the fix position is offset to the east from the DR position. The navigator determines set and drift from this offset and applies this set and drift to any DR position from 1300 until the next fix to determine an estimated position. He also resets the DR to the fix; that is, he draws the 180°T course line from the 1300 fix, not the 1300 DR.

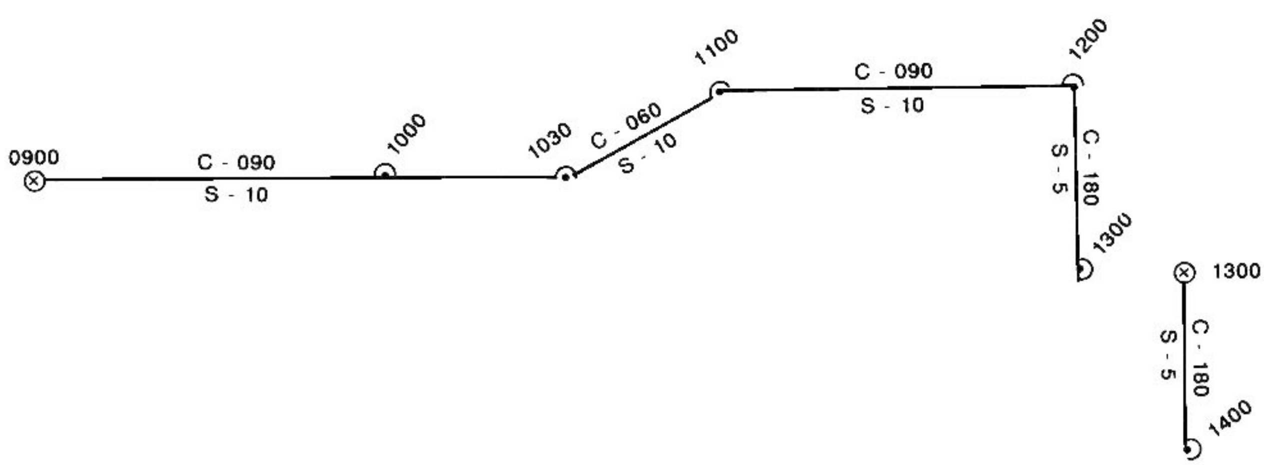


Figure 703. A typical dead reckoning plot.

704. Resetting The DR

Reset the DR plot to the ship's latest fix or running fix. In addition, consider resetting the DR to an inertial estimated position as discussed below.

If a navigator has not received a fix for a long time, the DR plot, not having been reset to a fix, will accumulate time-dependent error. Soon that error may become so significant that the DR will no longer show the ship's position with sufficient accuracy. If his vessel is equipped with an inertial navigator, the navigator should consider resetting the DR to the inertial estimated position. Some factors to consider when making this determination are:

(1) Time since the last fix and availability of fix information. If it has been a short time since the last fix and fix information may soon become available, it may be advisable to wait for the next fix to reset the DR.

(2) Dynamics of the navigation situation. If, for example, a submerged submarine is operating in the Gulf Stream, fix information is available but operational considerations may preclude the submarine from going to periscope depth to obtain a fix. Similarly, a surface ship with an inertial navigator may be in a dynamic current and suffer a temporary loss of electronic fix equipment. In either case, the fix information will be available shortly but the dynamics of the situation call for a more accurate assessment of the vessel's position. Plotting an inertial EP and resetting the DR to that EP may provide the navigator with a more accurate assessment of the navigation situation.

(3) Reliability and accuracy of the fix source. If a submarine is operating under the ice, for example, only the inertial EP and Omega fixes may be available for weeks at a time. Given a known inaccuracy of Omega, a high prior correlation between the inertial EP and highly accurate fix systems such as GPS, and the continued proper operation of the inertial navigator, the navigator may well decide to reset the DR to the inertial EP rather than the Omega fix.

DEAD RECKONING AND SHIP SAFETY

Properly maintaining a DR plot is important for ship safety. The DR allows the navigator to examine a future position in relation to a planned track. It allows him to anticipate charted hazards and plan appropriate action to avoid them. Recall that the DR position is only approximate. Using a concept called **fix expansion** compensates for the DR's inaccuracy and allows the navigator to use the DR more effectively to anticipate and avoid danger.

705. Fix Expansion

Often a ship steams in the open ocean for extended periods without a fix. This can result from of any number of factors ranging from the inability to obtain celestial fixes to malfunctioning electronic navigation systems. Infrequent fixes are particularly common on submarines. Whatever the reason, in some instances a navigator may find himself in the position of having to steam many hours on DR alone.

The navigator must take precautions to ensure that all hazards to navigation along his path are accounted for by the approximate nature of a DR position. One method which can be used is **fix expansion**.

Fix expansion takes into account possible errors in the DR calculation caused by factors which tend to affect the vessel's actual course and speed over ground. The navigator considers all such factors and develops an expanding "error circle" around the DR plot. One of the basic assumptions of fix expansion is that the various individual effects of current, leeway, and steering error combine to cause a cumulative error which increases over time, hence, the concept of *expansion*.

Errors considered in the calculation of the fix expansion encompass all errors that can lead to DR inaccuracy. Some of the most important factors are current and wind, compass or gyro error, and steering error. Any method which attempts to determine an error circle must take these factors into account. The navigator can use the magnitude of set and drift calculated from his DR plot. See section 707 below. He can obtain the current's magnitude from pilot charts or weather reports. He can determine wind speed from weather reports or direct measurement. He can determine compass error by comparison with an accurate standard or by obtaining an azimuth of the sun. The navigator determines the effect each of these errors has on his course and speed over ground, and applies that error to the fix expansion calculation.

As noted above, the error is a function of time; it grows as the ship proceeds down the track without a obtaining a fix. Therefore, the navigator must incorporate his calculated errors into an **error circle** whose radius grows with time. For example, assume the navigator calculates that all the various sources of error can create a cumulative position error of no more than 2 nm. Then his fix expansion error circle would grow at that rate; it would be 2 nm after the first hour, 4 nm after the second, and so on.

At what value should the navigator start this error circle? Recall that a DR is laid out from every fix. All fix sources have a finite absolute accuracy, and the initial error circle should reflect that accuracy. Assume, for example, that a satellite navigation system has an accuracy of 0.5 nm. Then the initial error circle around that fix should be set at 0.5 nm.

Construct the error circle as follows. When the navigator obtains a fix, reset the DR to that fix. Then, enclose that DR position in a circle the radius of which is equal to the accuracy of the system used to obtain the fix. Lay out the ordered

course and speed from the fix position. Then, apply the fix expansion circle to the hourly DR's. In the example given above, the DR after one hour would be enclosed by a circle of radius 2.5 nm, after two hours 4.5 nm, and so on. Having encircled the four hour DR positions with the error circles, the navigator then draws two lines originating tangent to the original error circle and simultaneously tangent to the other error circles. The navigator then closely examines the area between the two tangent lines for hazards to navigation. This technique is illustrated in Figure 705 below.

The fix expansion encompasses *all the area in which the vessel could be located* (as long as all sources of error are considered). If any hazards are indicated within the cone, the navigator should be especially alert for those dangers. If, for example, the fix expansion indicates that the vessel may be standing into shoal water, continuously monitor the fathometer. Similarly, if the fix expansion indicated that the vessel might be approaching a charted obstruction, post extra lookouts.

The fix expansion may grow at such a rate that it becomes unwieldy. Obviously, if the fix expansion grows to cover too large an area, it has lost its usefulness as a tool for the navigator, and he should obtain a new fix.

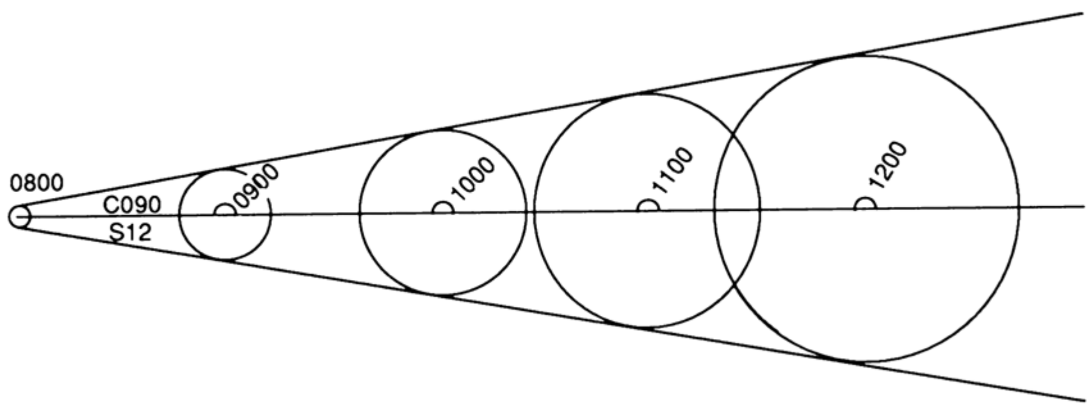


Figure 705. Fix expansion. All possible positions of the ship lie between the lines tangent to the expanding circles. Examine this area for dangers.

DETERMINING AN ESTIMATED POSITION

An estimated position is a DR position corrected for the effects of leeway, steering error, and current. This section will briefly discuss the factors that cause the DR position to diverge from the vessel's actual position. It will then discuss calculating set and drift and applying these values to the DR to obtain an estimated position. Finally, it will discuss determining the estimated course and speed made good.

706. Factors Affecting DR Position Accuracy

Tidal current is the periodic horizontal movement of the water's surface caused by the tide-affecting gravitational force of the moon. **Current** is the horizontal movement of the sea surface caused by meteorological, oceanographic, or topographical effects. From whatever its source, the horizontal motion of the sea's surface is an important dynamic force acting on a vessel moving through the water. **Set** refers to the current's direction, and **drift** refers to the current's speed.

Leeway is the leeward motion of a vessel due to that component of the wind vector perpendicular to the vessel's track.

Leeway and current effects combine to produce the most pronounced natural dynamic effects on a transiting vessel.

In addition to these natural forces, helmsman error and gyro error combine to produce a **steering error** that causes additional error in the DR.

707. Calculating Set And Drift And Plotting An Estimated Position

It is difficult to quantify the errors discussed above individually. However, the navigator can easily quantify their cumulative effect by comparing simultaneous fix and DR positions. Were there no dynamic forces acting on the vessel and no steering error, the DR position and the fix position would coincide. However, they seldom coincide. The fix is offset from the DR by a finite distance. This offset is caused by the error factors discussed above.

Note again that this methodology provides no means to determine the magnitude of the individual errors. It simply provides the navigator with a measurable representation of their combined effect.

When the navigator measures this combined effect, he often refers to it as the "set and drift." Recall from above that these terms technically were restricted to describing current effects. However, even though the fix-to-DR offset is caused by effects in addition to the current, this text will follow the convention of referring to the offset as the set and drift.

The set is the direction from the DR to the fix. The drift is the distance in miles between the DR and the fix divided by the number of hours since the DR was last reset. This is true regardless of the number of changes of course or speed since the last fix. Calculate set and drift at every fix.

Calculate an EP by drawing from a DR position a vector whose direction equals the set and whose magnitude equals the product of the drift and the number of hours since the last DR reset. See Figure 707. From the 0900 DR position the navigator draws a set and drift vector. The end of that vector marks the 0900 EP. Note that the EP is enclosed in a square and labeled horizontally with the time. Plot and evaluate an EP with every DR position.

708. Estimated Course And Speed Made Good

The direction of a straight line from the last fix to the EP is the **estimated track made good**. The length of this line divided by the time between the fix and the EP is the **estimated speed made good**.

Solve for the estimated track and speed by using a vector diagram. See the example problems below. See. Figure 708a

Example 1: *A ship on course 080°, speed 10 knots, is steaming through a current having an estimated set of 140° and drift of 2 knots.*

Required: *Estimated track and speed made good.*

Solution: *See Figure 708a. From A, any convenient point, draw AB, the course and speed of the ship, in direction 080°, for a distance of 10 miles.*

From B draw BC, the set and drift of the current, in direction 140°, for a distance of 2 miles.

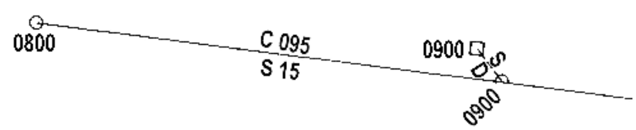


Figure 707. Determining an estimated position.

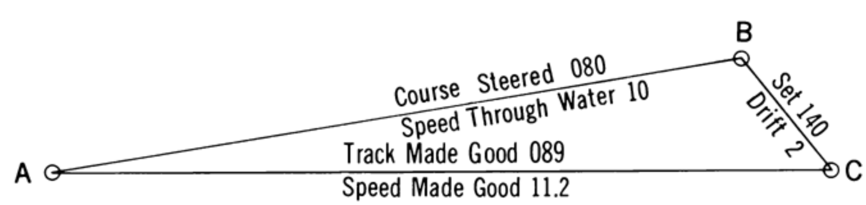


Figure 708a. Finding track and speed made good through a current.

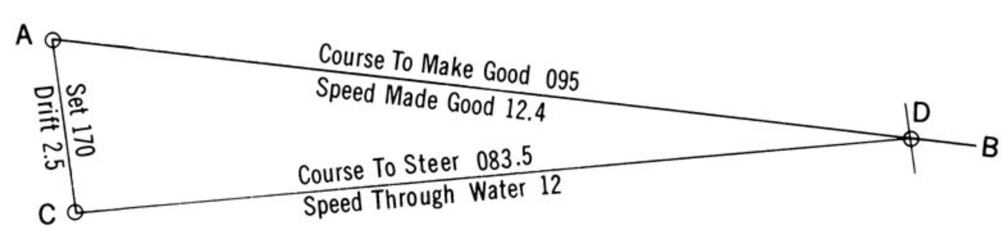


Figure 708b. Finding the course to steer at a given speed to make good a given course through a current.

The direction and length of AC are the estimated track and speed made good.

Answers: *Estimated track made good 089°, estimated speed made good 11.2 knots.*

To find the course to steer at a given speed to make good a desired course, plot the current vector from the origin, A, instead of from B. See Figure 708b.

Example 2: *The captain desires to make good a course of 095° through a current having a set of 170° and a drift of 2.5 knots, using a speed of 12 knots.*

Required: *The course to steer and the speed made good.*

Solution: *See Figure 708b. From A, any convenient point, draw line AB extending in the direction of the course to be made good, 095°.*

From A draw AC, the set and drift of the current.

Using C as a center, swing an arc of radius CD, the speed through the water (12 knots), intersecting line AB at D.

Measure the direction of line CD, 083.5°. This is the course to steer.

Measure the length AD, 12.4 knots. This is the speed made good.

Answers: *Course to steer 083.5°, speed made good 12.4 knots.*

To find the course to steer and the speed to use to make good a desired course and speed, proceed as follows: See Figure 708c.

Example 3: *The captain desires to make good a course of 265° and a speed of 15 knots through a current having a set of 185° and a drift of 3 knots.*

Required: *The course to steer and the speed to use.*

Solution: *See Figure 708c. From A, any convenient point, draw AB in the direction of the course to be made good, 265° and for length equal to the speed to be made good, 15 knots.*

From A draw AC, the set and drift of the current.

Draw a straight line from C to B. The direction of this line, 276°, is the required course to steer; and the length, 14.8 knots, is the required speed.

Answers: *Course to steer 276°, speed to use 14.8 kn.*

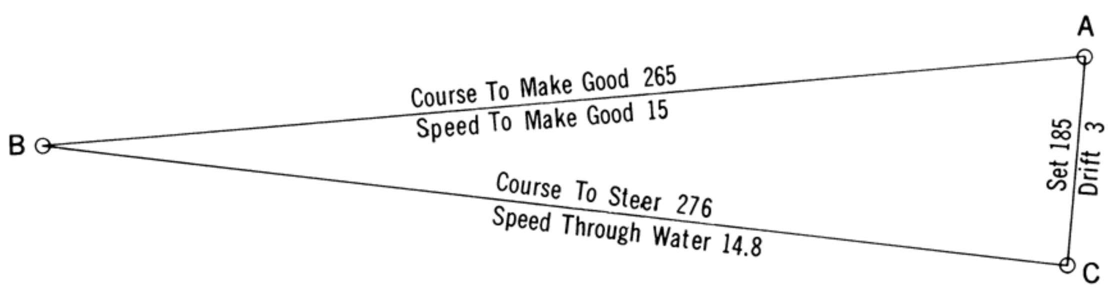


Figure 708c. Finding course to steer and speed to use to make good a given course and speed through the current.